THE PROCESSES OF TECHNOLOGICAL INNOVATION: A CONCEPTUAL SYSTEMS MODEL

by

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PREFACE

The George Washington University (Program of Policy Studies in Science and Technology) has prepared the following report for the Office of Invention and Innovation, National Bureau of Standards, Department of Commerce. The report presents the results of research that was stimulated and supported by the Office of Invention and Innovation under Contract #CST - 395, as a follow-on project to the Department of Commerce report published in January 1967, entitled "Technological Innovation: Its Environment and Management." Part of the funding for this contract was contributed by the Arms Control and Disarmament Agency, Department of State. Supplemental support for the project was provided under NASA Institutional Grant # NGR 09-010-030 to the Program of Policy Studies in Science and Technology.

The report was prepared by Ellis Mottur, Senior Staff Scientist, who served as Principal Investigator for this project. During the summer of 1967 helpful research assistance was afforded by Miss Carolyn Vetter, a graduate student at the Case Institute of Technology. Throughout the course of the project useful comments, questions and criticisms have been provided by various

associates of the Program of Policy Studies in Science and Technology, including: Guy Black, Clarence H. Danhof, John Hanessian, James E. Mahoney, and General Bernard A. Schriever, USAF (Ret.). Special thanks are due to Dr. Louis H. Mayo, Vice President for Advanced Policy Studies, whose continuing counsel and encouragement have contributed significantly to the successful completion of this project. Mr. Daniel V. De Simone, Director of the Office of Invention and Innovation, who imparted the initial stimulus for this research, provided throughout the project a combination of cooperation and constructive criticism that enhanced the end product considerably.

Of course, responsibility for the content of this report, along with censure for any errors or omissions, must be ascribed to the author.

Ellis Mottur

ELLIS MOTTUR
Principal Investigator

INTRODUCTION

It is commonly asserted and accepted that technological change characterizes our civilization and sets it apart from past ages. Although significant threads of technology have been interwoven in the strands of human history from time immemorial, it is only in recent years that the rate and ramifications of technological change have surpassed the 'critical mass' necessary to engender a continuous implosion exerting a pervasive impact on all facets of our society and affecting all aspects of our lives.

Technological change imparts awesome might to our military machines, inhibits the emergence of patterns of international stability, changes the once constant factors of the physical environment into variables subject to the vagaries of industry and agriculture, engenders congestion and confusion in our urban complexes, and opens the possibility of manipulating the genetic character of man himself. Simultaneous with its presentation of these manifold problems, technological change provides an apparently limitless profusion of opportunities: to modify the weather, exploit the vast resources of the ocean, explore the reaches of outer

space, drastically reduce disease and poverty, facilitate rapid world-wide communication and travel, expand the affluence of society, increase the range of public services, instill greater variety and creativity in our activities, and even enhance the quality of individual lives. Technology is clearly a two-edged sword: posing massive problems with every capability it confers, and affording new opportunities with each problem it poses. Earlier in this century H. G. Wells characterized civilization as a "race between education and catastrophe." We can now extend this aphorism to state that the race track itself is constantly shifting beneath our feet since it consists of an unpredictable sequence of unsettling technological changes.

To anticipate, assess, and affect the character of those changes, and to some extent control their consequences, has come to comprise what is perhaps the paramount problem of our time. Technological change has clearly emerged as a central concern of public policy. This concern extends to all facets and ramifications of technological change, including: (1) its capacity for unlimited extermination; (2) its propensity for concomitant contaminations; (3) its responsiveness

to public needs, demands, problems, and opportunities (including its potential for assistance in the resolution of complicated socio-economic problems); (4) its implications with respect to the institutional structure and values of our democratic society; and (5) its complex impact on the economy, as well as the reciprocal effects of the economic system on the rate and character of technological change. With respect to this last concern, it is becoming increasingly recognized that technological change is as fundamental a factor in the functioning of the economic system as is capital or labor. Although the precise nature of the relationship remains shrouded in obscurity, it is coming to be widely accepted that technological change is extremely important to sustained economic growth, and that public policies should be devised and directed at promoting technological change and encouraging its role in economic growth.

To wrestle successfully with this imposing complex of interrelated issues - to design and implement public policies capable of coherently coping with the wide array of problems involved - requires the utilization of a conceptual framework that realistically encompasses

the processes of technological innovation and systematically sets them forth within the socio-economic context in which they occur. This project has been devoted to the development and delineation of such a framework, and to the examination of its potential for application as an analytical tool in this area.

The framework that has been constructed consists of a conceptual systems model that focuses on: (1) the various ways in which the structure of socio-economic institutions and organizations, in combination with particular patterns of goals and resources, promotes or impedes the processes of technological change; and (2) the ways in which scientific knowledge is transformed into inventions, and inventions are incorporated in innovations that enter the wider socio-economic system where they are used and appraised and the results fedback to affect the further formulation of goals and policies and the related allocation of resources.

The systems model has been designed to facilitate the analysis and appraisal of research proposals and alternative public policies aimed at elucidating or enhancing the processes of technological innovation throughout our nation, with special emphasis on

proposals and policies directed at innovation in the civilian sector of the economy. Examples of the kinds of objectives that could be served by application of this model include:

(1) increasing the overall rate of technological innovation in our society;

(2) stimulating the introduction of innovation in technologically underdeveloped areas (including sectors and segments of the economy, as well as geographic regions of the nation);

(3) improving the effectiveness with which technological innovations are conceived and carried out;

(4) increasing the diffusion of technological innovations within industries and across industries and sectors of the economy;

(5) enhancing the responsiveness of technological innovation to the needs, opportunities, and demands of the society; and

(6) planning for the conservation of defense industry innovative resources in the event of substantial curtailments in defense spending, and for the effective transfer and utilization of such resources in other sectors of the economy.

This report provides a detailed description of the systems model and discusses its significance and the uses to which it can - and should - be put. Specifically the report covers the following: (1) the underlying assumptions, criteria, and concepts of the system; (2) the steps involved in the construction of the model; (3) the functioning of the model (i.e., the specific functions and interrelationships among functions that comprise the processes of technological innovation); (4) the range of problems encountered in practice in the fulfillment of these functions; (5) the general characteristics of technological innovation as exhibited by the system; (6) its implications; (7) its applications; and (8) summary and conclusion.

This introduction may be succinctly stated as follows: The character and consequences of technological change have become crucial to the course of our civilization. It is essential to take measures to assist in anticipating, assessing, and affecting the character of these changes, and in controlling their consequences. For such measures to prove most effective, they should be conceived and implemented within a coherent conceptual framework that realistically encompasses the processes

of technological innovation as they occur in the context of our socio-economic system. This report respectfully submits such a conceptual systems model for the critical consideration of researchers, practitioners, and policy makers in this area. If this endeavor appears to be overly audacious, isn't that usually the case with most innovations?

CHAPTER ONE

UNDERLYING ASSUMPTIONS, CRITERIA, AND CONCEPTS

A - Underlying Assumptions

> "For invention and innovation encompass the totality of processes by which new ideas are conceived, nurtured, developed and finally introduced into the economy as new products and processes; or into an organization to change its internal and external relationships; or into a society to provide for its social needs and to adapt itself to the world or the world to itself." (Department of Commerce Report, Technological Innovation: Its Environment and Management, January 1967, pg. 2)

It should be emphasized at the outset that this report refers to the processes of technological innovation in the plural. Technological innovation is not a simple, straightforward sequence of events that proceeds with deterministic regularity toward predictable ends. The singular term 'process' ascribes too much simplicity and uniformity to what is in reality an exceedingly involved set of processes that follow a complex course of events that is often highly creative and unpredictable. The success of most innovations in practice depends on the initiative, imagination, judgment, and commitment of particular individuals who are willing to place their time, talents, and reputations on the line in situations of considerable uncertainty and

risk. Even though innovative events, however, are usually complex, creative, and unpredictable, they do constitute a set of interrelated processes, rather than a collection of disconnected activities. The functions that are performed in practice to propel these processes forward are finite, identifiable, and subject to detailed analysis. The possible interrelationships among these functions are similarly limited in number and subject to systematic scrutiny and study, even though there are innumerable variations in the combinations and permutations of functions and interrelationships that may be exhibited in any particular innovational sequence.

To accept the above assumptions which underlie this model - and conceive of technological innovation as a set of interrelated processes subject to systematic analysis - does not in any way deny or denigrate the creative, unpredictable aspects of innovation or overlook the wide variations possible in practice. Acceptance of these assumptions, however, permits the construction of a coherent conceptual model which can assist in predicting those aspects of innovation that are predictable, in directing

those sequences of events that are subject to direction, and in structuring strategic elements of the socio-economic environment along lines designed to facilitate the flow of innovation.

B - Underlying Criteria

The underlying criteria to be met by the model derive from its purpose: to provide assistance to decision and policy makers in analyzing and appraising research proposals and policy alternatives aimed at elucidating or enhancing the processes of technological innovation. To fulfill this purpose the model must be broad enough to encompass all important aspects and kinds of technological innovation, flexible enough to fit the full range of variations in the circumstances through which innovations occur, and realistic enough to take account of the specific sorts of obstacles and opportunities encountered in practice in the processes of technological innovation.

Thus the model must span the full spectrum of activities from basic research through applied research, invention, development, engineering, and operations to eventual use and appraisal in the wider socio-economic system. It must prove applicable to all kinds of innovations, including: specific products or processes, composite products or processes, services, and complex socio-economic systems. It must permit wide variations in significant environmental factors (such as the tax

structure, the patent system, anti-trust regulations, etc.); and in the particular characteristics and interrelationships of the institutions, organizations, and individuals involved in any innovational sequence (such as government agencies, business firms, non-profits, academic institutions, individual entrepreneurs, etc.). Finally the model must prove capable of analyzing the specific kinds of problems - whether they be obstacles or opportunities - that are encountered in practice by the organizations and individuals responsible for innovative progress.

C - Underlying Concepts

The objective of this study was to develop as simple a model as possible that would meet the above criteria. Accordingly the model is based on extremely simple concepts. The underlying idea is that the processes of technological innovation can be described as complex combinations of interactions among three distinct factors: goals, resources, and technological knowledge. These three factors interact in a variety of ways in the context of varying institutional and organizational configurations so that any innovation can be described as a complex sequence of such interactions. Chart 1 below, The Transformation and Use of Resources in the Socio-Economic System, depicts one of the basic forms of interaction among these factors.

THE TRANSFORMATION AND USE OF RESOURCES IN THE SOCIO - ECONOMIC SYSTEM

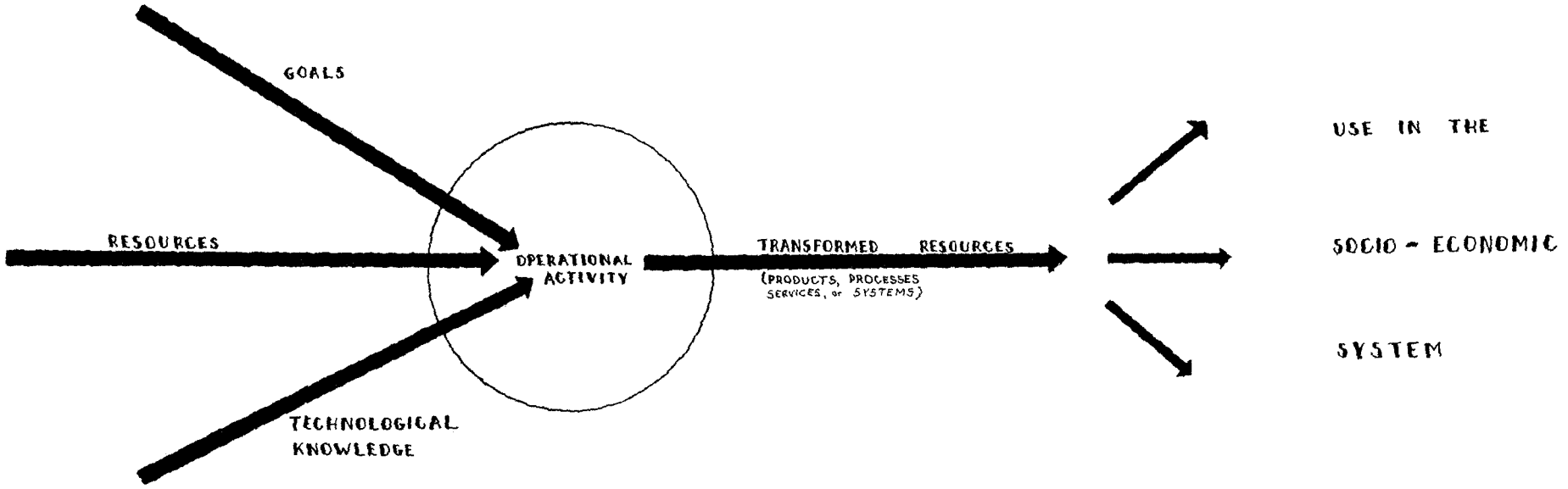


CHART 1

The above chart illustrates the extremely simple concept on which the model is based: The products, processes, services, or systems that are used within the socio-economic system result from the interaction of goals, resources, and technological knowledge within the context of some operational activity, such as a factory, farm, mine, etc. The mode of interaction is the application of the technological knowledge to the resources, in the context of the operational activity, in order to accomplish the goals. As a result of the interaction, some portion of the resources is transformed, thereby producing products, processes, services, or systems for use in wider segments of the socio-economic system.

The underlying interaction depicted in Chart 1 is constantly occurring throughout the socio-economic system in a variety of institutional and organizational contexts. Clearly only a small portion of these interactions can constitute technological innovations. Let us consider what properties the interaction must have in order for it to be properly classified as a technological innovation.

A technological innovation can be said to occur when the technological knowledge involved in the interaction results in the emergence of certain novel characteristics. These can take any one of three forms. The most obvious form is novelty in the output of the activity, i.e., the products, processes, services, or systems that result from the operational activity exhibit new or significantly altered characteristics. This situation constitutes an instance of technological innovation whenever the novelty occurs as a result of the application of technological knowledge. A second form of technological innovation occurs whenever technological knowledge leads to novelty in the pattern of resources provided as input to the activity. Thus, even when the output of products, processes, services, or systems may not be substantially altered, there may be significant changes in the pattern of resources utilized to produce those outputs (e.g. the use of different raw materials to produce an end product with substantially unchanged characteristics). A third major form of technological innovation occurs whenever technological knowledge leads to significant novelty in the framework

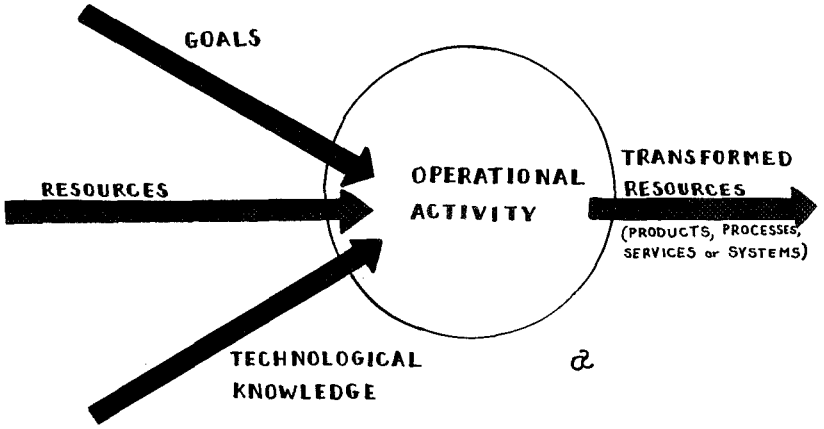
or conduct of the operational activity itself (such as changes in manufacturing methods to effect cost reduction) even when the inputs and outputs remain essentially unchanged. Of course particular innovations can combine two or three of these basic forms.

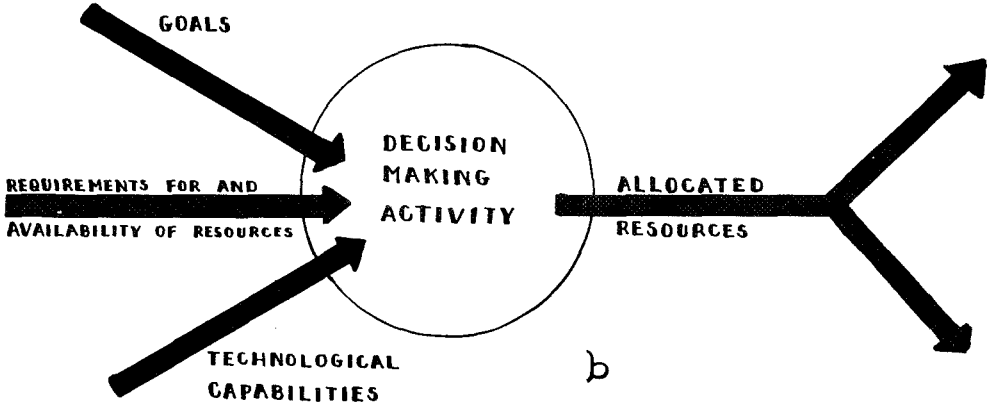
An extremely important point that should be borne in mind throughout the entire discussion of the model is that the technological knowledge involved in a technological innovation does not itself have to be new. There are innumerable instances in which technological knowledge that has been in existence for many years eventually triggers a technological innovation. Sometimes, of course, new technological knowledge leads fairly rapidly to a technological innovation. Increasing the rapidity of such application is a primary objective of many technology transfer programs; but rapidity of application of new technological knowledge is not an essential defining characteristic of technological innovation. The important defining characteristic is not the newness of the technological knowledge that is employed, but the novelty of its application. It is the novel way in which technological knowledge is applied - in a new situation, in a new

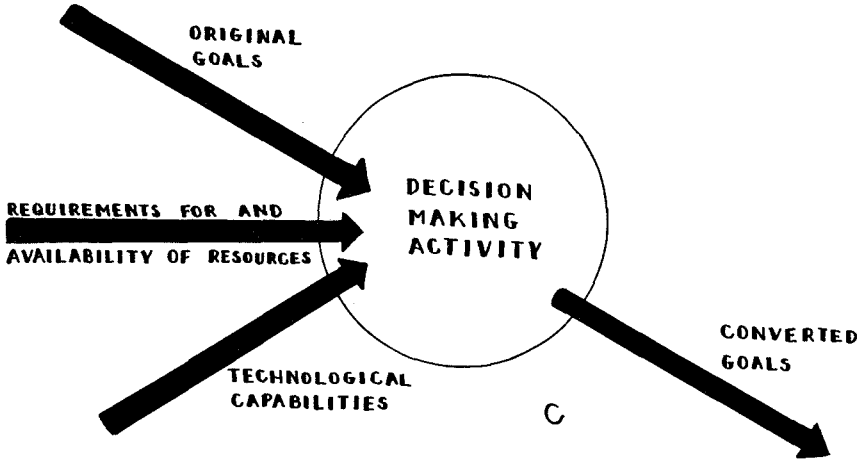
combination with goals and resources, in a new kind of operational context, or to produce new kinds of products, processes, services, or systems - that is essential to technological innovation; the knowledge itself does not have to be novel.

Chart 1, however, depicts only one of the basic forms of interaction among goals, resources, and technological knowledge. Chart 2 below, The Interaction of Goals, Resources, and Technological Knowledge, illustrates three other basic forms of interaction among these elements.

THE INTERACTION OF GOALS, RESOURCES, AND TECHNOLOGICAL KNOWLEDGE







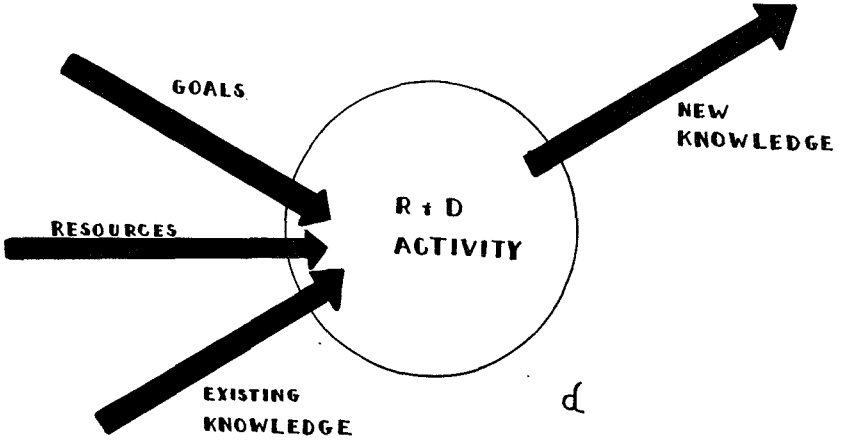


CHART 2

At the top left-hand side of Chart 2 above we see a repetition of the diagram contained in Chart 1 (2a). At the top right-hand side of Chart 2 we see the interaction of goals and information regarding resources and technological knowledge in the context of some decision making activity (such as the top level of a government agency or the top management of a corporation) (2b). The result of this kind of interaction is an allocation of the resources, instead of a transformation. In this situation the goals do not interact directly with resources and technological knowledge, but rather with information about the resources and technological knowledge. The interaction involves information regarding the requirements for and the availability of resources and information concerning present and potential technological capabilities. The decision making activity considers this information in the light of its goals and allocates the resources accordingly.

In the lower left-hand side of Chart 2 we see the interaction of original goals and information regarding resources and technological knowledge in the context of some decision making activity (such

as a government office sponsoring R&D or a corporate management echelon above that of the laboratory director) (2c). The result of this kind of interaction is a conversion of the goals. In this situation again the goals do not interact directly with resources and technological knowledge, but rather with information regarding the requirements for and the availability of resources, and information concerning present and potential technological capabilities. The decision making activity considers its original goals in the light of such information, and converts the goals accordingly.

In the lower right-hand side of Chart 2 we see the interaction of goals, resources, and existing scientific knowledge in the context of some R&D, invention or engineering activity (such as a laboratory or engineering pilot project) (2d). In this situation the resulting output is new knowledge. The focus of the activity is not on the transformation or allocation of resources or the conversion of goals, but on the creation of new knowledge. The goals may be hypotheses to be proved or disproved in the case of basic research, technological capabilities desired to be achieved in practice in the

case of development, or highly specific engineering objectives in the case of production engineering. The resources include scientific and engineering equipment and facilities, materials and energy sources, as well as the physical, biological, or behavioral entities or phenomena that are under investigation. Within the context of the R&D activity, the resources interact with existing scientific and engineering knowledge in some pattern of relationships imposed in part by the goals. The result is the creation of new knowledge, even when the new knowledge merely leads to discarding an hypothesis, or reports the failure to achieve a particular engineering objective.

The above diagrams illustrate four basic forms of interaction among goals, resources, and technological knowledge as envisaged in the model. Obviously the preceding description of these interactions is highly oversimplified. In order for these essentially simple concepts to serve as effective analytical tools, they must be expanded and elaborated until they are applicable in practice to the complex of concrete activities with which we are concerned.

Particular innovations consist of extremely complex sets of such interactions. Consider, for example, the transformation depicted in diagram 2a above. The resource input to most operational activities is itself usually the output of some previous operational activity. For example, component parts entering into an operational activity engaged in manufacturing assembly operations may themselves be products produced by some other manufacturing operation. Even if they are not the product of a previous resource transformation, resource inputs are generally the result of some prior resource allocation activity (as in 2b). Thus the resource input to any operational activity usually consists of the convergence of several series of other resource transformation and allocation activities.

Similarly, for an operational activity to prove effective in practice, its goals must be in the form of specific operational objectives towards which its efforts can be precisely directed. Usually such operational objectives are the end product of a series of goal conversions (as in 2c) carried out by various individuals, organizations, or networks of organizations

engaged in the identification, selection, priority ordering, and formulation of goals.

By the same token, for technological knowledge to be most useful to the operational activity, it must be in the form of precise operational specifications (such as blueprints, detailed processing instructions, etc.). Such specifications usually are the end result of extensive engineering efforts, which themselves must directly or indirectly draw on the pool of available technological knowledge created in the course of various R&D programs (as in 2d). Drawing on the pool of available technological knowledge is, of course, no simple matter, involving as it does the complex scientific, technological, and industrial communication systems with their multitude of attendant problems.

Thus we see that each of the input arrows entering the operational interaction depicted in figure 2a is itself the product of a complex series of other interactions of goals, resources, and technological knowledge that have to be successfully carried out before the final transformation can occur, and the resulting innovation can enter the socio-economic system.

Even this statement of the situation, however, is highly oversimplified. It omits consideration of the crucial communication links and feedback loops interconnecting the various goal conversion, knowledge creation, and resource allocation and transformation activities. Generally for these activities to be at all effective, they cannot function independently of one another, but must involve considerable intercommunication and feedback.

For example, if engineers do not receive some preliminary indication of what the specific operational objectives are likely to be, it is improbable that they can develop precise operational specifications that will facilitate fulfillment of those objectives. Similarly if the individuals involved in goal conversion are not aware of emerging engineering capabilities and limitations, it is unlikely that they will specify operational objectives that are realistic and that take full advantage of new opportunities. At the same time, in order to orient their activities effectively, the individuals and organizations engaged in the allocation and preliminary transformation of resources should be aware of the ultimate operational objectives and

engineering approaches to their attainment that are likely to be adopted. Reciprocally, information concerning the kinds of resources that can be made available is important to the effectiveness of goal formulation and engineering activity. Two-way communication between the goal formulation function and user communities is also essential in order to ascertain user needs, recognize new opportunities, induce user acceptance when appropriate, and appraise user reaction to products, processes, services, or systems.

Thus we see that to account realistically for the normal flow of activities and communication among the organizations and individuals involved in the processes of technological innovation, we rather rapidly move from the simple illustrations of Chart 2 to an increasingly complex set of interactions. The systems model described in this report attempts to take account of the full range of factors and interactions involved in the processes of technological innovation. In addition, it has been designed to meet the criteria set forth in Section B above: it provides for all sorts of innovations, including products, processes,

services, and systems; it spans the spectrum from basic research through use and appraisal in the socio-economic system; and it permits consideration of alternative environmental conditions and varying configurations of institutions and organizations that may be involved in specific innovational situations.

Therefore, despite the fact that the model is based on the essentially simple concepts depicted in Chart 2, it constitutes a fairly complex system when considered in its totality. The model consists of sixty-one interrelated steps or functions that can be thought of as comprising the processes of technological innovation. Because of its overall complexity, we shall defer detailed examination of the model as a whole and discussion of its various implications and applications, until we have described the step-by-step construction of its chief components.

CHAPTER TWO

CONSTRUCTION OF THE SYSTEMS MODEL

This chapter describes the step-by-step construction of the chief components of the model; detailed discussion of the functioning of the system will be reserved for Chapter Three.

A - Technological Activities in the Socio-Economic System

This section illustrates the extremely simple manner in which construction of the model was undertaken, with the identification of four major modes of technological activity within the socio-economic system. Chart 3 below depicts the overall socio-economic system as including four major modes of technological activity: research; invention and development; other engineering; and operations. The dashed line across the chart separating these activity modes from the rest of the socio-economic system is purely for purposes of exposition. Obviously these and all related activities that collectively comprise the processes of technological innovation are integral parts of the socio-economic system. To facilitate comprehension and utilization of the model, however, we shall in subsequent charts depict the socio-economic system as a separate construct. We shall be enabled thereby to illustrate the impact

of technological activities on the socio-economic system and the reciprocal impact and inputs from the socio-economic system to these activities. The artificiality of this expository separation should be borne in mind throughout all subsequent discussion of the model.

TECHNOLOGICAL ACTIVITIES IN THE SOCIO- ECONOMIC SYSTEM

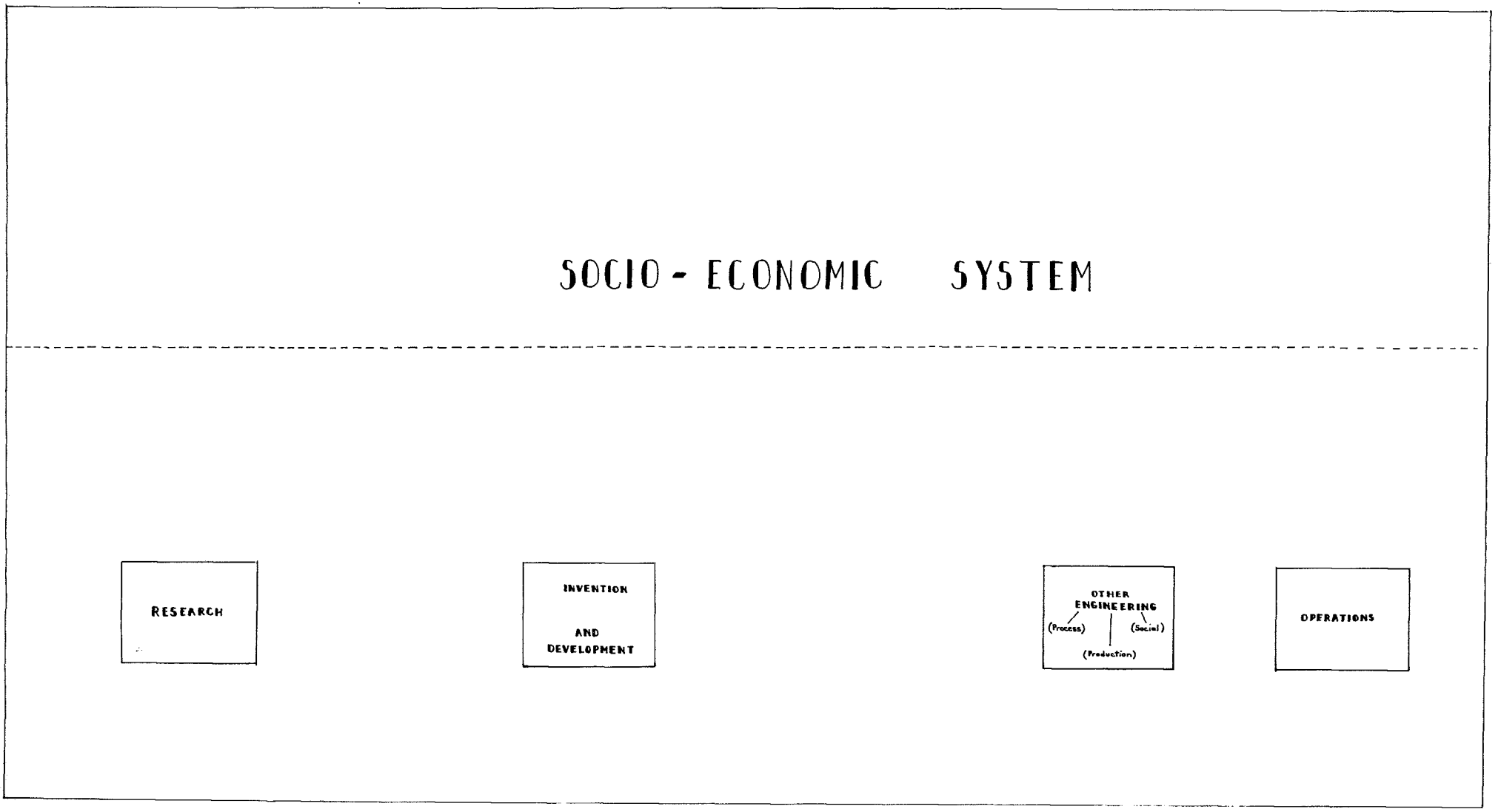


CHART 3

What is meant by four major modes of technological activity in Chart 3 above? The activities integrally involved in the processes of technological innovation range all the way from pure scientific research to the financing of new business enterprises, from the systems development of new technology to the market research designed to predict its reception in the socio-economic system. Within this extensive assortment of activities, we have selected and designated certain sets of activities as the 'major modes of technological activity'. By this designation we refer to those activities directed at the creation of new technological knowledge and the application of that knowledge to transform certain resources into new products, processes, services, or systems for use in wider segments of the socio-economic system. By creation of new knowledge, we mean to encompass not only fundamental scientific discovery, but also all varieties of scientific and technological information, including specific engineering instructions designed to guide operational activities.

In practice the manifestations of these modes of technological activity can - and do - occur in a wide variety of institutional and organizational contexts.

Thus depending on the particular case or problem under consideration, the research mode of activity could be carried out within the context of a national laboratory (such as Brookhaven), or a corporate research division, or a non-profit research institute, or an academic research project, etc. Similarly the context of invention and development activity could range anywhere from a giant aerospace corporation engaged in a major space development effort, to a medium-size corporation's development of a new commercial product, to the classic of the individual inventor working alone in his attic. In the same way the institutional-organizational contexts of particular engineering or operational activities can vary extensively.

Now why have we chosen four major modes of technological activity, and how do we define and distinguish among them? In point of fact the various modes of technological activity are not distinct and separate as indicated in the above chart, but rather interpenetrate and overlap one another extensively, in ways that vary considerably from one set of innovational circumstances to another. While it is helpful for purposes of analysis to differentiate among certain

major modes of technological activity, the numbers of such modes chosen and the defining characteristics ascribed to them are subject to a wide variety of definitions and interpretations. For instance, if it appeared desirable in the future, the model could be expanded and elaborated to include among its primary modes activities such as: basic and applied research, mission oriented or non-mission oriented research, exploratory and advanced development, design, pilot, or production engineering, tooling, initial operations, high-volume operations, etc. The important point is that attempts to apply the concepts of this model to actual instances of innovation indicated the desirability of delimiting at least four major modes of technological activity. In order to keep the model as simple as possible, we have not introduced any additional differentiations in its basic structure, although such differences are taken account of in its application to particular problems.

Before proceeding to define the four activity modes (research, invention and development, other engineering, and operations), it is important to emphasize that the definitions employed are arbitrary.

This arises not from any capriciousness on the part of the author, but rather from the failure to discern any consensus in the literature regarding distinctions among these activities. To the extent there is any consensus on these matters, it is generally confined to portions of the literature and is often incompatible with definitions employed in other portions.

How one tends to define the various modes of technological activity depends both on the professional point of view from which one approaches the problem, and on the particular set of circumstances one is considering. The economist tends to focus on different aspects of innovation from those on which the business administrator concentrates; and the entrepreneur injects a unique point of view of his own. The research scientist views innovation from a different perspective from that of the development engineer, who in turn views these processes differently from the production engineer.

The particular circumstances under consideration are as important to the definition problem as is one's professional point of view. The distinction between 'research' and development' in a large federally funded aerospace program is quite different from the

distinctions that could be made with respect to large scale corporate commercial research and development, which also exhibit differences from the situation in which individual engineer-entrepreneurs are pushing their inventions. Similarly the distinction between 'invention and development' and 'other engineering' is extremely difficult to define with precision in ways acceptable to all relevant points of view and applicable to all innovative situations. The difficulty in this case is compounded by the fact that engineering refers both to a set of academic disciplines and professional groups, and also to certain sorts of activities in which engineers engage. Engineers may - and often do - engage in activities that do not fall within the 'other engineering' mode of the model. These include management, administration, sales, and educational activities, as well as research, invention and development, and operations.

In addition to these difficulties in distinguishing among the major modes of technological activity delimited in the model, there are of course comparable problems involved in differentiating varieties of activity within each major mode. The classic

distinction between basic and applied research is frequently highly fuzzy in practice; often what is basic research from one point of view is applied research from another perspective. In addition there are many other overlapping ways of differentiating different sorts of research activities: mission or non-mission oriented, theoretical or experimental, conducted in a government, academic, or industrial environment, etc. In the same way it is extremely difficult to draw hard and fast distinctions between 'invention' and 'development' and among the different categories of engineering.

In short, the major modes of technological activity constitute far more of a complex, overlapping continuum than they do a set of separate distinct activities; yet some such distinctions are essential to undertake effective analysis of innovative processes. The variety of ways in which one could introduce and draw such distinctions is as endless as the variety of professional points of view and problem areas involved. Our examination of the various segments of the literature did not reveal any consensus of definitions on these matters. Accordingly we have developed arbitrary definitions of these major modes of technological

activity which fit the conceptual system of the model and appear applicable in practice to the various problems and specific cases that have been considered.

In the model the modes of activity (research, invention and development, other engineering, and operations) are differentiated as follows:

Research: The research mode refers to all that activity in which scientists and engineers engage that results in the identification, delineation, interpretation, and affirmation or negation of new scientific and engineering possibilities; or the re-interpretation or re-integration of previously known scientific or engineering possibilities. This is an extremely broad definition which includes research in engineering as well as in science and which covers all the varieties of research (basic, applied, mission oriented, non-mission oriented, theoretical, experimental, etc.). In effect this definition views research as an activity whereby scientists and engineers are incessantly engaged in the extension and exclusion, the simplification and clarification, the interpretation and re-interpretation of the realm of what is possible. In terms of this definition the primary product of research is knowledge about what is - and what isn't - possible.

Invention and Development: In the model this mode refers to the activities in which scientists and engineers engage to take various scientific and engineering possibilities and render them realities; i.e., to create concrete instances that embody those possibilities. Of course this activity usually involves narrowing the scope of possibility since most scientific and engineering possibilities include a number of parameters that can range over a variety of values. Successful invention or development usually includes the designation of specific values for various of the parameters; thus invention and development activity results in particular instances or manifestations of more general sets of possibilities. The end product of invention and development is technological knowledge that shows how to make a certain set of scientific possibilities actually occur in practice in a particular way.

Other Engineering: This mode refers to the activity in which engineers engage to take inventions or developed technology (i.e., particular technological manifestations of certain scientific possibilities) and adapt the technology in order to render it useful in practice in some segment of the socio-economic

system. The technology is adapted by altering its characteristics or its relationships to various external factors. Some examples of the kinds of adaptations encompassed by 'other engineering' should help convey the meaning of this definition. When the innovation is a product, 'other engineering' may refer to adaptations that: permit larger scale or higher volume production; decrease certain cost factors; increase various performance factors; decrease the time cycle for production; modify the composition or character of component parts or raw materials; alter associated parameters such as environmental conditions within which a product must be produced (e.g., temperature, pressure); make it possible to produce the product with the facilities and equipment of a particular plant; etc. When the innovation is a process, 'other engineering' could include (in addition to the above considerations) the application of the process to other kinds of materials or products. When the innovation is a service or a system, 'other engineering' could include all of the 'social engineering' necessary to assure the effective introduction of the service or system into some segment of the socio-economic system. In general, 'other

engineering' involves adapting the invention or developed technology to assure that it will actually fit the requirements, capabilities, and limitations of an existing or projected operational activity which will subsequently introduce the innovation into the socio-economic system. The end product of 'other engineering' activity is technological information in the form of precise technical instructions to the operational activity.

Operations: This major mode refers to those activities carried out to transform resources in order to produce and distribute new products, implement new processes, provide new services, or set in operation and sustain the functioning of new systems - depending on the particular kind of technological innovation under consideration. Thus the operational activity is that depicted on Charts 1 and 2a above. The other major modes of activity (research, invention and development, and other engineering) are all variations of Chart 2d.

In short, as the four major modes of technological activity are envisaged in the model: (1) research shows what is possible; (2) invention and development activity makes what is possible actually happen in a particular case; (3) 'other engineering' takes that

particular case and adapts it for useful incorporation in portions of the socio-economic system; and (4) operations (following the technical instructions of engineering) actually introduces the innovation into the socio-economic system. These distinctions should become increasingly clear as we discuss the functioning of the systems model in detail.

B - The Role of Communication

While the function of communication is extremely important in almost all fields of human endeavor, its role in science and technology is unusually unique, essential, and pervasive. Scientific and technical information comprises both the raw material and the end product of all research, invention, development, and engineering activity. Even the tangible prototypes produced by various engineering efforts are but material parts of complex packages of information designed to function as models or 'templates' for subsequent operational activities. Accordingly the communication systems of science and technology both envelop and serve as the substratum for all scientific and technological activity. Chart 4 below, The Substratum of Communication, introduces the Scientific and Engineering Communication System and the Technological-Industrial Communication System into our model.

THE SUBSTRATUM OF COMMUNICATION

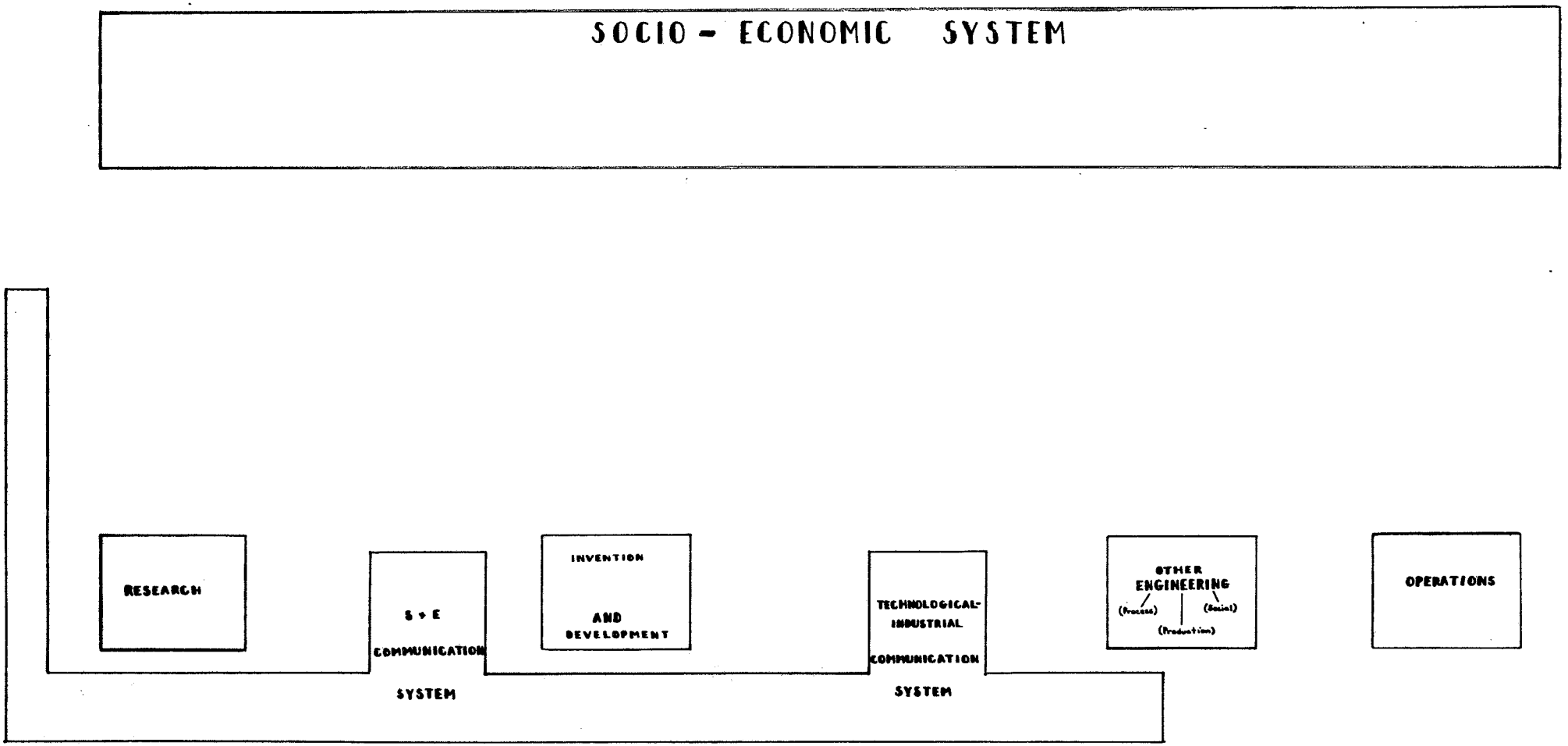


CHART 4

The above chart merely indicates the underlying position of these communication systems relative to the major modes of technological activity. The peculiar shape of these systems on the chart is not reflective of any particular characteristics, but is intended solely for display purposes: to minimize the number of overlapping lines in the final illustration of the overall model.

As depicted in Chart 4, the model distinguishes two broad, interrelated communication systems: the science and engineering communication system, and the technological-industrial communication system. The first of these is conceived of as including all communication of substantive scientific and engineering information, whether it is formal or informal, written, verbal, or electronic. Thus this communication system embraces articles in scientific or engineering journals, preprints of papers, talks at symposia, specialized data services in fields such as particle physics, informal communication among members of elite 'invisible colleges' of experts, etc. The technological-industrial communication system is conceived of as including all communication of substantive technological information

regardless of the form in which it occurs (formal or informal, written, verbal, or electronic). The two systems overlap considerably in the area of engineering, where there is an interchange of information across the indefinite boundary separating the systems (as indicated on the chart). The technological-industrial communication system includes much of the rapidly proliferating technical report literature, trade journals, business house organs, government programs such as the Office of State Technical Services, the wide variety of business and industrial conferences and meetings, patent licensing, and a vast mass of proprietary or otherwise restricted information that is communicated only within extremely limited confines.

Before considering the ways in which the major modes of technological activity interact with one another through the medium of these communication systems, it is important to make the point that the word 'system' is in reality something of a misnomer. Neither the science and engineering nor the technological-industrial communication system is truly a system in the sense of constituting a coherent whole that functions in some sort of rationally interrelated manner.

On the contrary, they both consist of exceedingly complex mazes of institutions, organizations, groups, and individuals that interact - when they do interact - in oftentimes ineffectual or confusing ways. Research and development is frequently duplicated for lack of relevant information that was available somewhere in the overall communication network. Important ancillary information regarding instrumentation, experimental techniques, etc. it often not adequately described and entered into the system so that it can be used by others. Results of research in one field or discipline that could be of value to other fields or disciplines are rarely disseminated across disciplinary lines with alacrity commensurate to their potential significance. At the same time non-proprietary technological knowledge that is available somewhere in the overall system is often not acquired and utilized by industries and firms that could make good use of it. While the dissemination and use of scientific information at the basic research end of the spectrum appears to be somewhat more widespread than the diffusion of technological knowledge throughout industry, neither of these so-called systems can be

viewed as effectively facilitating the flow and utilization of scientific and technological information. Rather than systems, they are in fact much more complex mazes of miscellaneous activities - occasionally in search of some system. Nevertheless for want of a better term, we shall continue to refer to them throughout the report as the scientific and engineering communication system, and the technological-industrial communication system.

Chart 5 below, The Flow of Substantive Scientific and Technical Information, illustrates the ways in which the major modes of technological activity interact with one another through the medium of the communication systems:

THE FLOW OF SUBSTANTIVE SCIENTIFIC AND TECHNICAL INFORMATION

SOCIO - ECONOMIC SYSTEM

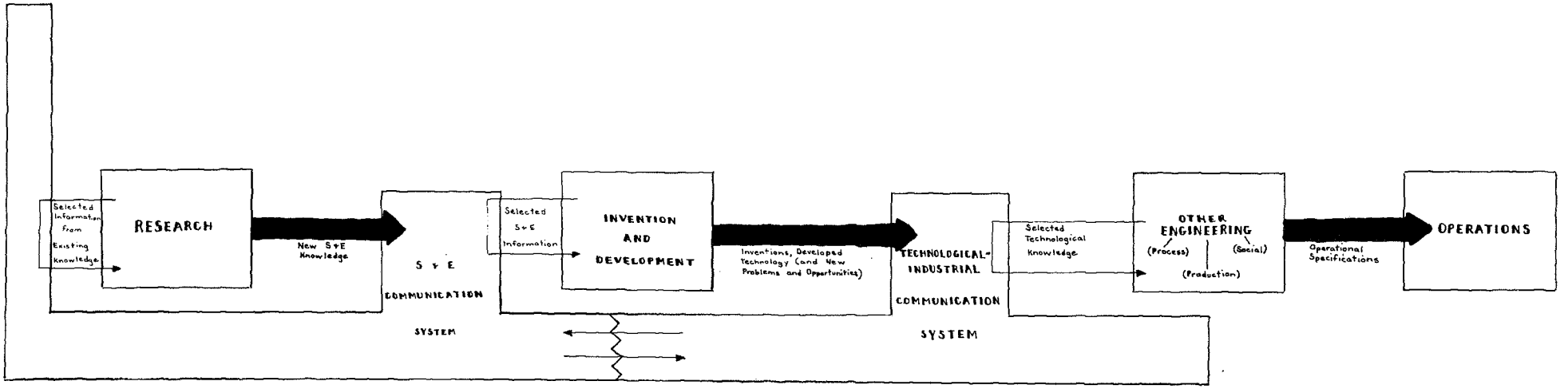


CHART 5

Chart 5 above illustrates the flow of substantive scientific and technological knowledge from basic research all the way through to the operational activity that will introduce the innovation into the socio-economic system. The pattern of information flow illustrated on this chart is essentially different from that depicted on most flow charts. Most flow diagrams show the movement of some substance (such as manufactured goods, inventory items, funds, energy, or information) across a system, with one or more input points providing the impetus to propel the substance across the system. The flow indicated on the above chart and throughout this systems model, however, is fundamentally different. It involves not only the notion of propulsion across a system, but also the concept of searching among a number of possibilities and selecting out certain specific possibilities to be pursued. The extensive use of this concept of selection from a range of possibilities, in combination with the more familiar notion of propulsion across a system, enables this model to be far more reflective of the underlying realities of technological innovation - in particular its creative, unpredictable aspects -

than is possible with most conventional models of innovative processes. It may also be noted that the use of this selection function in other segments of the system than those depicted on the above chart permits the model to take into account and assess the responsiveness of technological activities to the needs, opportunities, and demands of the socio-economic system. These attributes of the model will be explored further in subsequent sections of the report.

Let us examine the flow pattern presented on this chart. At the left-hand side of the chart we see the institutions, organizations, and individuals engaged in research activity reaching into the existing store of scientific and engineering knowledge, and selecting out certain information considered relevant to their concerns. This act of selection is not a one-shot affair, of course, but occurs frequently throughout the course of most research activities. The kind of information sought varies not only for different sorts of research projects or different disciplines or fields, but also for the various stages of progress of particular projects. For example, at the start of a

project, a scientist may be especially interested in scientific knowledge that will help him define problems or formulate hypotheses. At another stage he may be largely interested in learning of pertinent experimental techniques or of alternative verifications for particular facts he has uncovered. At a final stage of writing up his results for formal entry into the communication system, he may be most interested in locating appropriate citations for specific points in his paper. In any event selections are made from existing knowledge, and the research groups utilize that knowledge, in conjunction with their resources and goals, to create new science and engineering knowledge. (Perhaps it should be reiterated in this connection that: the resources include materials, energy sources, and physical, biological or behavioral entities or phenomena under investigation, as well as facilities, equipment, and professional manpower; and the goals include hypotheses to be validated, modified, or discarded, as well as broad missions to be fulfilled or specific research project goals.)

The new scientific and engineering knowledge is entered into the science and engineering communication system. This may occur in a variety of ways, both formal and informal, including written presentations, verbal communication, input into computer data systems, etc. This function also may be carried out a number of times throughout the course of a particular project. For example, a scientist may inform some close associates of his preliminary results at an early stage of his research. At a slightly later stage he may write a letter to some journal about his work. Still later he may deliver a preliminary paper at a regional symposium. Subsequently he may deliver a more elaborate paper at an international scientific congress (having previously dispatched preprints of the paper to colleagues in his 'invisible college'). Finally he may submit a formal final paper to a scientific journal. Some time after its publication, an abstract journal may digest the paper and publish the abstract. The fact that the function of entering new knowledge into the communication system generally takes place sooner or later in one form or another should not be construed

to mean that the function is normally fulfilled effectively, completely, or sufficiently promptly.

The institutions, organizations, and individuals engaged in invention and development activity similarly reach into the science and engineering communication system, and select out certain information considered relevant and valuable to their goals. Here again the function is usually performed a great many times throughout the course of a particular project. Utilizing the selected information, in conjunction with its goals and resources, the organization carries out its invention and development activities and produces inventions, developed technology, and/or new problems and opportunities. The results of these efforts are entered into the technological-industrial communication system - to some extent at least. The degree to which results are entered into this system, and their dissemination and availability once entered, pose major problems at this point of the system. In any event, results of invention and development activities are generally entered into the system to some extent, even if only for extremely restricted distribution and use. In the case of a large corporation that

has its own development and 'other engineering' activities, the communication system may largely consist of the relationships and procedures whereby these two groups in the corporation communicate substantive technological information with one another; i.e., the new knowledge may be transferred directly from the development organization to the 'other engineering' group (if higher management within the corporation so directs).

The organizations engaged in 'other engineering' similarly select from the store of available technological knowledge, specific technical information that appears relevant to their problems or objectives. Making use of such information, in conjunction with their engineering objectives and resources, they carry out their engineering activities and produce technological knowledge in the form of precise operational specifications. These are transferred directly to the appropriate operational activity (after certain decision making functions are carried out as discussed in subsequent sections of this report).

Having briefly described the fundamental flow of substantive scientific and technological knowledge

across the spectrum of technological activities, we can now turn to the other components of the systems model which perform a variety of essential related functions.

C - The Science and Engineering Educational System

Chart 6 below, The Science and Engineering Educational System, introduces this important constituent of the system. As presently constructed, the model does not attempt to penetrate this area in any detail; instead it merely illustrates the overall relationship of the educational system to the processes of technological innovation. At the far left of the chart we see the science and engineering educational system receiving goals and resources from the socio-economic system. (This does not preclude the educational system from also generating various of its goals internally; but certain of the goals are determined within the wider socio-economic system and provided to the educational system.) At the bottom center of the chart we see institutions, organizations, and individuals engaged in educational activities reaching into the science and engineering communication system and the technological-industrial communication system, and selecting out certain scientific and technical information to be utilized in the educational processes in which these groups are engaged. (The problems involved in these

activities are treated later on in the report; here it may merely be noted that the function is apparently being performed less adequately for the technological-industrial communication system than it is for the science and engineering communication system.) At the far right of the chart we see the results of the various educational activities. The educational system provides the socio-economic system with new science and engineering manpower, and is also presumed to provide enhanced public understanding of science and technology (although the degree to which such understanding is imparted is open to some question). In any event, to the extent such public understanding does eventuate, it necessarily has some effect on the determination and formulation of goals with respect to technological innovation in the socio-economic system: thereby serving a feedback function in the overall model. Finally, as is the case with all such matters, the educational system provides the socio-economic system with further requests for resources.

THE SCIENCE AND ENGINEERING EDUCATIONAL SYSTEM

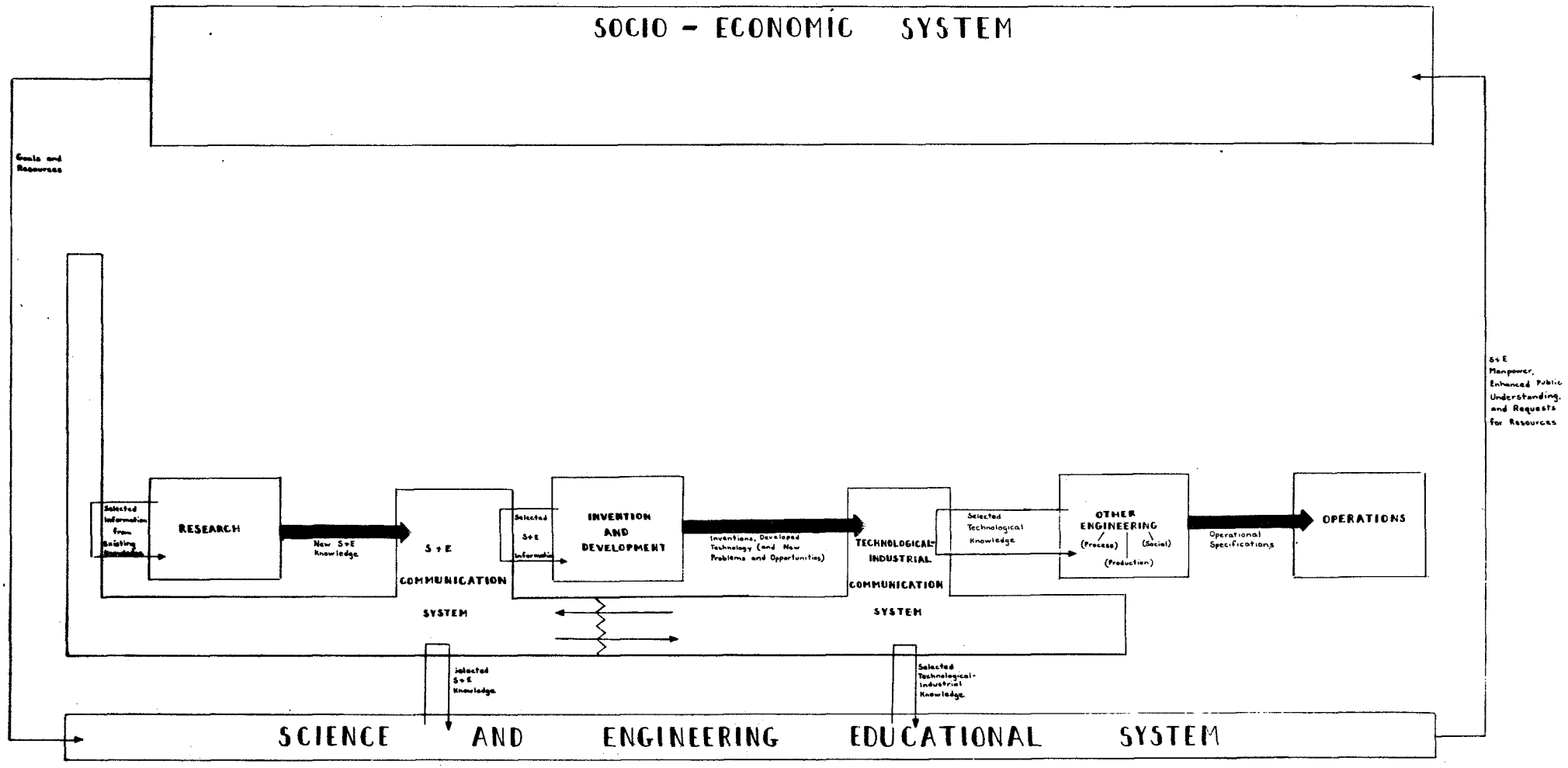


CHART 6

D - Interactions Between Technological Activities and the Socio-Economic System

In this section we shall begin to examine the sequence of important interactions that must take place between technological activities and the socio-economic system in order for technological innovations to occur. Chart 7 below, The Internal Technological Gap, indicates the extensive chasm that has to be crossed in order for these interactions to take place.

THE INTERNAL TECHNOLOGICAL GAP

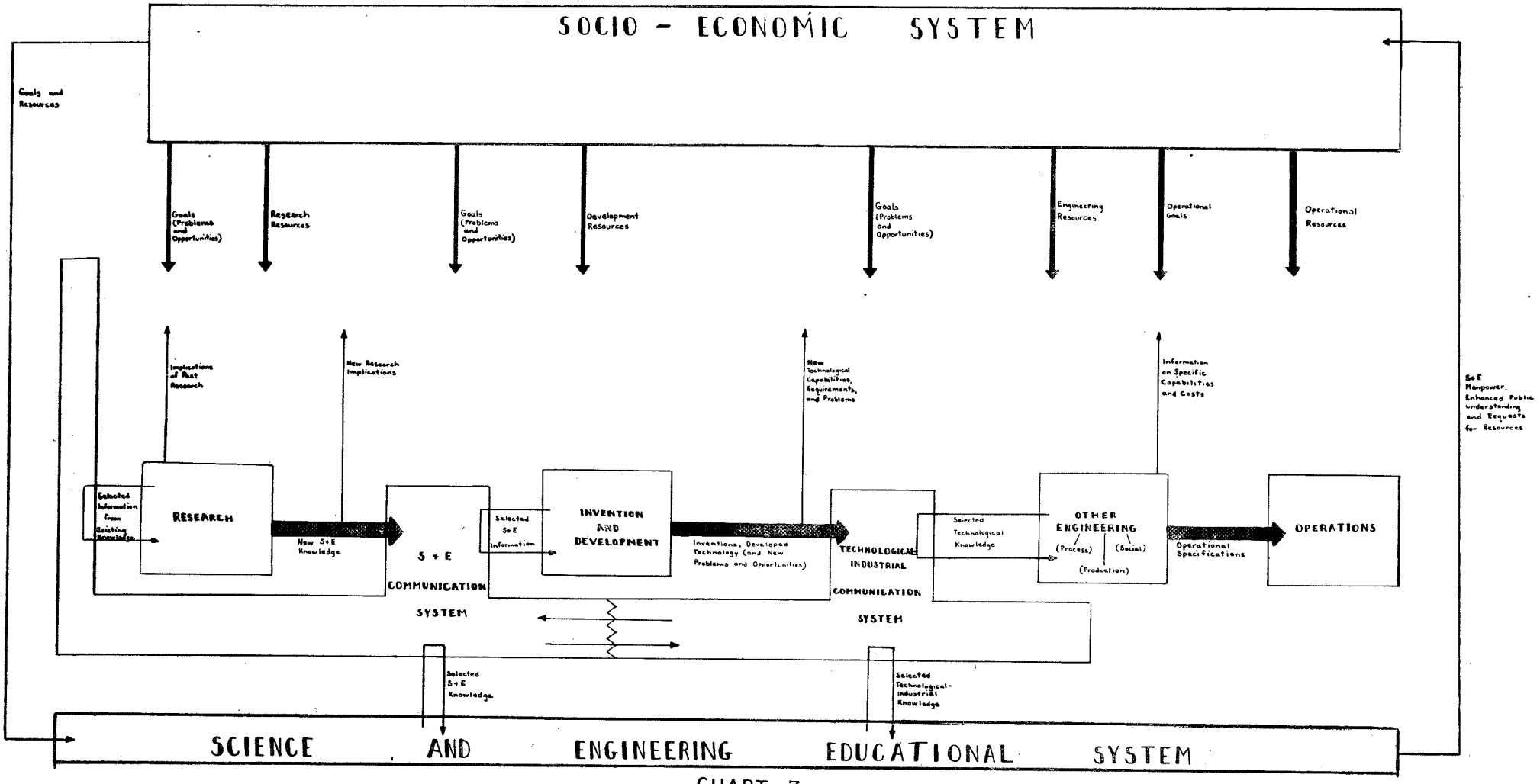


CHART 7

Viewing the above chart we see a series of arrows moving upward from the technological activity spectrum toward the socio-economic system, and a similar series of arrows moving downward from the socio-economic system toward the activity spectrum. The arrows do not meet, but rather leave a widespread void which we have chosen to call 'the internal technological gap' (to distinguish it from the external technological gap between nations resulting from their differing technological capabilities). Before considering the nature of this gap and the way in which it is surmounted, let us examine the specific arrows entering the gap from both sides.

The arrows moving down from the socio-economic system are all of two kinds: goals or resources. The goal arrows refer to goals for technological activity which have been determined by non-technological segments of the socio-economic system. The term goals is employed in the broadest sense imaginable, to include: problems, opportunities, objectives, limitations - indeed any set of factors intended to influence the direction or nature of activity in the technological activity spectrum (research, invention

and development, other engineering, operations). Resources are also conceived of very broadly to include: manpower (both professional and technical), as well as facilities, equipment, materials, energy sources, funds, and any other resources that can be provided by the socio-economic system for utilization in technological activities (such as the allocation of certain bands of the radio frequency spectrum for research in radio astronomy).

It may be noted at this point that many analysts in this area rightly regard scientific and technical information as a form of resource. While this is certainly a completely valid concept, it is not employed in this systems model because of the central role of scientific and technical information in the processes of technological innovation. A large part of these processes, centering in the activity spectrum, consist of the acquisition, consumption, creation, and dissemination of scientific and technical information. In order, therefore, for the system to accord adequate attention to technological knowledge, this factor must be considered apart from other kinds of resources.

Viewing the arrows moving upward from the activity spectrum toward the socio-economic system, we see that they all represent forms of information. Reading across the chart from left to right we see: first the implications of past research; then the implications of new research; then information about new technological capabilities, requirements, and problems; and finally information on specific capabilities and associated costs. Each of these arrows represents information, but it is a kind of information that is fundamentally different from the substantive technological information that moves across the activity spectrum horizontally. The information moving toward the socio-economic system is not substantive scientific or technical information. Rather it is information <u>about</u> the substantive knowledge; information that expresses the **<u>implications</u>** of the substantive knowledge for certain segments of the socio-economic system; information that indicates the expected <u>significance</u> of the substantive knowledge to the socio-economic system.

Now in order for the goals and resources of the socio-economic system to be effectively imparted to the activity spectrum, the socio-economic system must

be cognizant of the implications and significance of emerging technological capabilities and problems. Similarly to recognize those implications of substantive technological knowledge that are significant to the socio-economic system, one must be cognizant of existing and emerging socio-economic goals and resources. In short, the effectiveness of technological innovation is dependent on the repeated interaction of socio-economic goals and resources with the implications of substantive technological knowledge.

Chart 7, however, indicates that this interaction does not occur naturally; indeed that there is a vast void between the socio-economic system and the activity spectrum which must be spanned before this interaction can take place. What causes this gap and what is its significance?

The 'internal technological gap', as we have termed it, is largely a gap in communication (although this designation does not in any way diminish the difficulty of surmounting the gap). The persons in our society engaged in research, invention and development, other engineering, and technological operations employ special terminologies and jargons

peculiar to their areas of activity. Much of what they have to say is not intelligible to the people in the socio-economic system who determine and formulate goals and who acquire and allocate resources. These individuals similarly employ private languages of their own which are just as unintelligible to the scientists and engineers. The communication problem, however, is far more than a matter of special terminologies and jargons; for not only do these individuals speak different languages, but they also lead different sorts of lives with different practices, different problems, different perspectives. Mere translation of the terms they use would not resolve the problem; most of them would find it extremely difficult to comprehend what the other fellow was driving at, even if they knew the literal meaning of his terms. Thus this communication problem is as deep-seated as it is pervasive.

In short, the effective determination of goals and allocation of resources for technological activities are dependent on the early and astute assessment of the implications of substantive technological knowledge;

and the effective derivation and delineation of these implications are in turn dependent on sound foreknowledge regarding emerging patterns of socio-economic goals and resources. As indicated on our chart, however, the 'internal technological gap' or communication chasm separating these segments of our society precludes the direct interaction of these elements.

Despite this gap though, technological innovation does of course occur in our society. In point of fact it occurs more extensively and effectively in our society than in any other past or contemporary civilization. It may not occur as widely or as well as we would like it to, but it does in fact occur. Somehow the 'internal technological gap' is bridged; the communication chasm is crossed. How is this feat accomplished? Considering the central role in technological innovation of the interaction of goals, resources, and the implications of substantive technological knowledge, it is likely that better understanding of this interaction can provide valuable insight into the nature of innovative processes and into ways of enhancing their effectiveness.

Chart 8 below, Conversion Processes, introduces a significant new set of functions into our model, which serve to bridge the gap and propel the processes of technological innovation forward.

CONVERSION PROCESSES

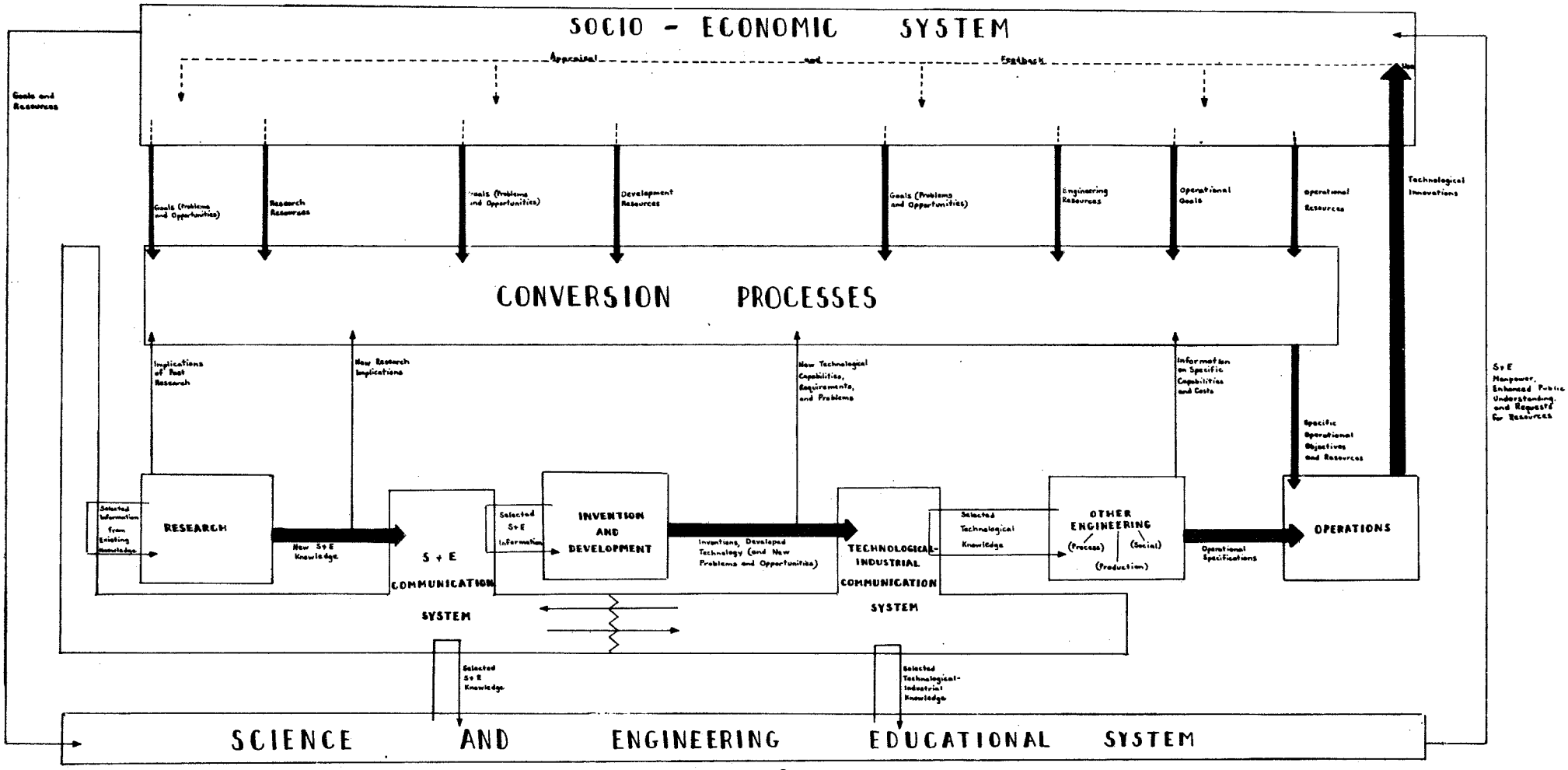


CHART 8

The above chart depicts a set of functions called conversion processes which span the entire model from the basic research end of the spectrum through operations. In the next chapter we shall consider these processes in detail; here we shall merely indicate their effects, significance, and general characteristics.

The net effect of these conversion processes is shown at the far right of the chart. As the end result of a whole sequence of conversion processes, we have the input to the operational activity of specific operational objectives and resources. These are combined, within the context of the operational activity, with technological knowledge in the form of precise operational specifications provided by the engineering activity. The result is the transformation of certain of the resources into the technological innovation (as shown earlier in Charts 1 and 2a) which enters the socio-economic system where it is used and appraised, and the appraisals fedback to affect the future formulation of goals and allocation of resources. Thus the conversion processes complete the dynamics of the systems model, and enable the full flow of activities involved in the processes of technological innovation to occur.

What are the major functions involved in what we have called conversion processes? First is the conversion of certain general goals of the socio-economic system into specific goals, presented in a form that is comprehensible to individuals in the activity spectrum and capable of influencing the direction of their efforts. Second is the conversion of resources provided by the socio-economic system into a form that is useful to the organizations in the activity spectrum, e.g., the conversion of financial resources into facilities. It should be noted that in the case of resources, conversions are not always necessary at this organizational level; frequently the resources provided by the socio-economic system can be directly transferred to the organizations in the activity spectrum (where they can be used as is, or converted within the activity spectrum when necessary). Third is the important function of coupling goals and resources together and providing them to the activity spectrum in a combined package so that specific resources can be directed toward specific goals. Fourth is the conversion of information on the implications of substantive technological knowledge. These implications

are converted into proposed programs, projects, or policies which are submitted for approval to other decision making agents in the socio-economic system.

All of these conversion processes are exceedingly complex and interrelated. For example the conversion of the implications of substantive knowledge is not merely a matter of converting a specific implication into a proposed program or project. On the contrary it usually involves a multitude of activities including: selections among various implications; the coupling together of a number of selected items; their joint consideration in conjunction with various goals and expectations regarding resource availability; the development of complex packages of such factors that constitute proposed programs, projects, or policies; and the specific formulation of these proposals in a form suitable for the decision makers to whom they are to be submitted. Such proposals to decision makers in the socio-economic system can, of course, be either accepted or rejected; or various modifications can be requested, thereby triggering new sequences of program development and formulation. Once a proposed program, project, or policy is accepted, it not only

serves to guide the input of coupled goals and resources to the activity spectrum, but it also feeds back into the socio-economic system to affect the subsequent determination of goals and the allocation of resources.

With the preceding description of the construction of the components of the model as background, we are now in a position to discuss the processes of technological innovation in more detail. Chapter 3 below discusses these processes as they occur in a major portion of the model, centering around the invention and development activity. (Chapter 4 then extends the description of these processes to the entire model.)

CHAPTER THREE

THE PROCESSES OF TECHNOLOGICAL INNOVATION: AS RELATED TO INVENTION AND DEVELOPMENT ACTIVITIES

A - General

This chapter focuses on a sequence of sixteen of the sixty-one functions included in the model. Employing the numbering scheme set forth in Chapter Four below, these sixteen functions are designated as Steps 16 through 31. These functions are the ones that center around the invention and development activities. Following the discussion of the processes of technological innovation in this major portion of the model, the reader will be in a much better position to comprehend the description of the full model set forth in Chapter Four.

Before proceeding to a discussion of Steps 16 through 31, it is important to call attention to certain general characteristics of the model which are particularly pertinent to the examination of those functions. First is the wide range of variations possible in the environmental conditions, and institutional and organizational characteristics and relationships which exert a major impact on the ways in which the various functions are performed in practice. The environmental conditions include factors in the national

environment (such as tax and patent laws and anti-trust policies); and factors in the environment of particular regions or industries (such as the attitudes of the banking community in a certain region or the depreciation regulations regarding a particular industry). The institutional and organizational factors include the policies and practices, goals and resources of particular institutions and organizations, as well as the relationships among institutions and organizations (i.e., the configuration of institutions and organizations involved in any innovational sequence).

These institutional and organizational configurations can vary considerably; the range of functions performed by a single institution or organization can vary both horizontally and vertically in the model. Thus at one extreme a single, large scientifically-oriented corporation could span the entire model both horizontally and vertically. It could have its own research, development, engineering, and operational facilities; its middle management groups could perform conversion functions all along the model; and its top management, its board of directors, its industry association, and the various government agencies

engaged in its regulation could perform the various socio-economic functions with respect to its activities. Such a corporation could also have its own scientific and technical information service, thereby embracing part of the communication system; and through its own training programs, it could extend its reaches into the educational system of science and engineering. Contrasting with this situation, each of the functions in an innovational sequence could be carried out by a separate organization. Actually in many involved innovational events, single functions are often performed by complex networks consisting of a number of organizations.

To simplify the discussion of the model, we shall use the following symbols for each of the institutional and organizational variables: the organization or network of organizations engaged in exercising the socio-economic functions (goal determination, program approval or rejection, resource allocation, etc.) is designated as S, with appropriate subscripts to indicate the area of the model involved (S_r, S_d, S_e, S_o for research, invention and development, other engineering,

and operations respectively). The organization or network of organizations engaged in exercising the conversion functions is designated as C_r, C_d, C_e, and C_o respectively. Similarly the organization or network of organizations engaged in carrying out the technological activities is designated as A_r, A_d, A_e, and A_o respectively. The science and engineering communication system is designated as U_s; the technological-industrial communication system as U_I; and the educational system as E. It should be noted that these symbols apply not only to organizations, but also to individual inventors, entrepreneurs, financiers, etc. (or groups of such individuals) who may be involved in carrying out certain of the functions in various innovational situations.

The second general characteristic of the model to be borne in mind is that the sequence in which the functions are performed is also subject to variation. For example, specific innovational sequences may start at a number of points in the model (such as 'other engineering' rather than basic research). Irrespective of where a particular sequence starts, it is not always necessary for it to traverse all the remaining steps from the starting point on. Of those functions

which are carried out in a particular sequence, some are often performed implicitly or by default, rather than explicitly or with conscious deliberation, and, of course, of the functions which are carried out, many may often be performed poorly. In addition, as we have pointed out earlier, various steps or functions may occur repeatedly within one sequence (e.g., the function of selecting relevant information from the existing store of scientific knowledge). Finally, the model is capable of considerable recyclings within any innovational sequence.

As we examine the specific functions involved in the model, the manifestations and meaning of these variations will become clearer. At this stage of the discussion, it is merely necessary to emphasize that the model provides a framework of interrelated functions, in which one can vary: environmental conditions, institutional and organizational characteristics and configurations, and the specific sequences of functions performed in any innovational event. Thus the model may be thought of as a fundamental framework by means of which one can trace out the particular patterns, paths,

or routes traversed in any innovational sequence.

The preceding points should provide valuable background for the following discussion of the specific functions, and should themselves be considerably clarified in the course of that discussion.

B - Invention and Development

Chart 9 below, Invention and Development, illustrates the processes of technological innovation centering around invention and development activities. The sequence starts with Step 16, signified by the arrow entitled 'new research implications', moving upward into the conversion area from the horizontal flow of substantive knowledge entering the science and engineering communication system. The sequence ends with Step 31, signified by the arrow entitled 'new technological capabilities, requirements, and problems', moving upward into the conversion area from the horizontal flow of substantive knowledge entering the technological-industrial communication system. Thus we shall consider the processes of technological innovation from the point at which new research knowledge is created with implications for invention and development activities, until the point at which new technological capabilities, requirements, and problems have been delineated with implications for further engineering activities. We shall describe each step in turn, and attempt to elucidate the function involved by considering some of the major problems often encountered in practice in efforts to fulfill the function effectively.

INVENTION AND DEVELOPMENT

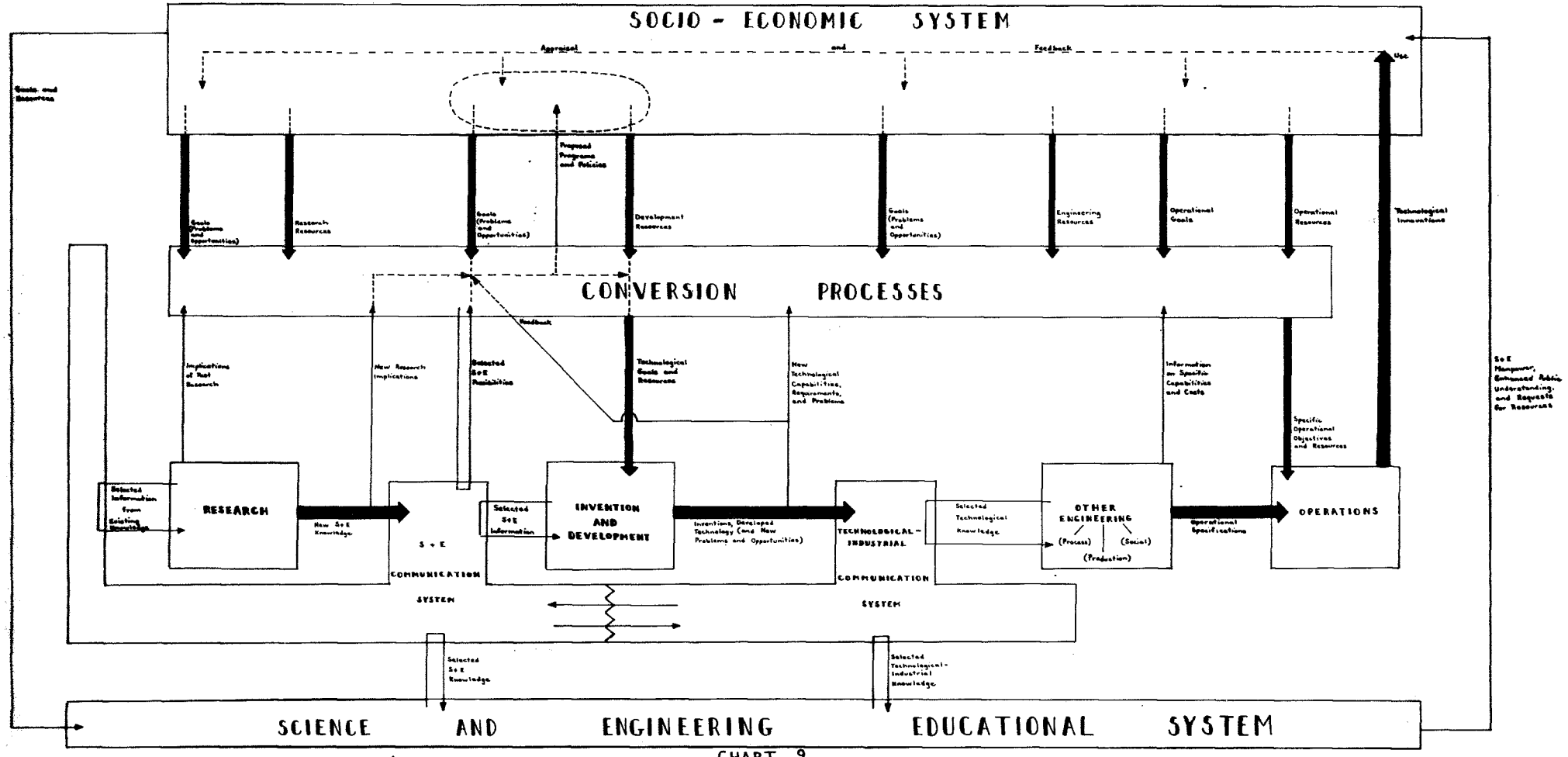


CHART 9

Step 16: Transmission to conversion organization (C_d) of the implications of new science and engineering knowledge with respect to development.

New science and engineering knowledge resulting from research consists of a core of substantive knowledge which is entered into the science and engineering communication system. Surrounding the core of new substantive knowledge is a 'penumbra' consisting of various implications. Certain of these implications concern the conduct of research activity itself. For example, there may be implications with respect to the future direction of the particular project from which the new knowledge emerged. At the same time there may be implications for other ongoing projects in the same discipline or same area of investigation. In addition there may be implications regarding other areas of research, other disciplines, or other kinds of problems. Some implications will pertain to multi-disciplinary areas. Some will arise in basic research and pertain to applied research, and vice versa. All of these implications impinge on further research; they are a form of feedback to

the decision makers engaged in conversion processes affecting the direction of research activities. The form of feedback we have been discussing incidentally is not shown on Chart 9. It appears on Chart 10 depicting the full model in Chapter Four. We shall not consider those implications here.

In this chapter we are concerned with those implications of new science and engineering knowledge with respect to various development possibilities, such as new areas of development that can now be pursued, or certain avenues of development which no longer appear feasible. They may be implications which shed light on developments already in process, or for which one has been planning. In any event in Step 16 new research implications with respect to development are transmitted to some individual or organization engaged in conversion processes. This is a function which could obviously be extremely important in the processes of technological innovation. Nevertheless it is not generally carried out with respect to the development implications of most new research knowledge. Even when it is performed, it is not necessarily done so most effectively.

What are some of the major problems that may be involved in fulfilling this function? An initial problem often encountered in this area is that of accepting responsibility to carry out this function in the first place. Research organizations rightly focus on their own research activities, and on communication within the science and engineering community. Such organizations are usually not concerned with or even capable of effectively discerning and transmitting the development implications of new research knowledge. In recent years a few organizations have emerged which attempt to perform the specialized function of discerning the development implications of new research knowledge, and attempting to communicate or exploit them. For the most part, however, whatever discernment of development implications may occur has to be undertaken by the research organization which created the knowledge; or by individual scientists and engineers who themselves recognize the development significance of the research results, and somehow attempt to communicate that significance to decision makers who can act on it.

Discussion of this problem points up an important value of the model. By clearly distinguishing among the diverse functions included in technological innovation, the model highlights the various facets of the problems involved. Thus it focuses on these facts: that this is a distinct function which research organizations often do not recognize; that they are not very much motivated to undertake it, nor particularly well equipped to carry it out effectively; and that the science and engineering communication system does not include many organizations which specialize in this function. Despite the vital importance of this function to the processes of technological innovation, for the most part it is not being carried out to the extent or with the degree of effectiveness that is both desirable and possible. By delineating this function and indicating its role in the processes of technological innovation, the model suggests the possibilities of offering new incentives, undertaking educational activities, creating new institutional arrangements, or encouraging the emergence of specialized organizations that would promote the more effective fulfillment of this function.

Once an organization has accepted the responsibility for this function, it often has the problem of identifying, selecting, inducing, or creating an appropriate conversion organization to which it can transmit the implications and which can carry out the required conversion processes (those numbered below as Steps 18, 19, 20, and 21). For example, a scientist or engineer who has been engaged in research may perceive certain implications concerning important inventions that could be achieved on the basis of that research, leading to a commercial product that he thinks would be highly marketable. If he has been working in a contract research laboratory, to whom would he present the development implications of this research so that action could be taken to exploit these possibilities? (Of course there can be many complicating factors involved, such as those that would be posed if the research had been conducted under a government contract precluding commercial exploitation of the results. In such a case, even if the individual could present the implications to an appropriate conversion organization, the structure of the system might prevent his realizing any reward for his perception. Yet the very perception of these implications might be a creative act in our socio-

economic system of considerable significance. It is important that our system provides more effective mechanisms whereby individuals can transmit development implications they have discerned and whereby their perception will be properly rewarded.) In any event there often may be a problem in finding an appropriate organization to carry out the necessary conversion processes. After having located an appropriate conversion organization and established effective relationships with it, there might be a considerable problem in preparing the implications of the substantive knowledge and the associated estimates of resources required to exploit that knowledge in a form that will be effective for presentation to the conversion organization (which might have quite a different level of comprehension of the technical aspects of such matters).

In reflecting on the functions set forth in this and the next chapter and on the various problem areas described, it should be constantly kept in mind that the mix and intensity of problems in any case will depend on the particular circumstances. The problems involved in discerning and transmitting development implications of new research will vary in the large scientifically -

oriented corporation with its own research and its own development facilities, in the non-profit research institute, in the academic laboratory, etc. In almost all cases, however, this function (regardless of whether and how it is performed) will be important to the processes of technological innovation and will present some mix of these problems.

Step 17: The socio-economic system (S_d) transmits goals for development to a conversion organization (C_d).

Perhaps the major problem in this area is that of determining the goals which are to be transmitted. These goals, of course, include problems, opportunities, objectives, limitations, etc. To prove effective, their determination must take account of all relevant socio-economic considerations such as market appraisals, legal problems, financial constraints, political pressures, public opinion, etc. Determination of such goals is an extremely difficult and inadequately understood function; yet it is, of course, critical to the processes of technological innovation.

Even after goals have been determined, there is often a major problem of assigning priorities to them. This problem is particularly pressing and difficult with respect to broad social issues, since the decision making structure of the Federal Government and of the society-at-large is not especially well suited or effective at the balancing of various priorities among important technological problems and goals. After goals have been determined and assigned appropriate priorities, there is often a problem of deciding whether it is desirable to foster and/or support development activity directed toward those goals. The determination in this instance is dependent, in part, on one's expectations regarding relevant scientific and engineering possibilities.

Step 18: C_d searches the science and engineering communication system in order to select various scientific and engineering possibilities pertinent to its goals.

This is a particularly important and interesting function, although it is very often not performed in present-day practice. There are, however, certain conversion organizations which do attempt to carry out

this function. For example, some of the large science-oriented corporations have special information services (either within their corporations or to which they subscribe) that attempt to carry out this function for the corporation. It has frequently proved extremely useful when this function has been carried out. Many innovations introduced into the socio-economic system by large corporations with extensive in-house R&D facilities have actually been based on new science and engineering knowledge created by others. The corporations have learned of this knowledge, acquired it, and exploited its possibilities for their own purposes. This phenomenon does not in any way impart a lessening in the importance of in-house research and development. It is likely that there is an intimate connection between a firm's in-house R&D capabilities and its ability to locate and appraise science and engineering possibilities elsewhere. Nevertheless to the extent that certain firms have been in a position to search the science and engineering communication system for possibilities pertinent to their goals, they have often profited from the exercise of this function. Many organizations, of

course, neither possess this capability, nor the resources which would permit them to develop the capability on their own. These limitations, however, do not preclude the exercise of this function by specialized information organizations which could provide this service to firms engaged in related conversion processes.

Major problems that occur with respect to this function are as follows: First, recognition of the importance of performing the function. Second, determination of the criteria or standards of relevance to be used in recognizing and selecting scientific and engineering possibilities pertinent to the goals to which one is committed. This is an extremely difficult problem, which involves not only the determination of the criteria but the delineation of the methods for applying these criteria in particular cases. A third problem with respect to this function is the establishment of an effective relationship between the conversion organization and the communication system of science and engineering. Such a relationship would involve factors such as what scientific and engineering journals the organization subscribes to, what kinds of scientific

and engineering meetings its staff are encouraged to attend, what sorts of specialized information services it makes use of, and so forth. A final major problem with respect to this function is that of actually locating and obtaining the relevant information within the science and engineering communication system, after effective relationships have been established and criteria of relevance have been determined. Locating and obtaining relevant information within the science and engineering communication system poses an enormous problem, to which a great deal of attention has been directed in recent years, but which is still a long way from effective resolution.

Step 19: C_d selects from relevant science and engineering possibilities specific possibilities to be pursued.

The conversion organization (C_d) may be confronted with a range of science and engineering possibilities, arising from a variety of sources. Some may come (through Step 16) as implications of new research directed to C_d, either by a research organization to which it is related (in the case of a large corporation) or by some independent source not organizationally

related to C_d. Other possibilities may come (through Step 18) from the science and engineering communication system, either through deliberate searching or through fortuitous discovery. Other possibilities may come (through Step 28 discussed below) as feedback from other invention or development activities over which C_d has cognizance. (This function is represented on the Chart as the intersection within the conversion segment of the arrows signifying Steps 16, 18, and 28.)

The major problems involved in fulfilling this function all cluster around the central issue of appraising alternative scientific and engineering possibilities pertinent to certain goals and choosing among them. Despite the tremendous importance of this area, very little substantial work has yet been done in analyzing it; and we are even lacking a promising methodology for approaching the problem. Often even when the decision maker is aware of a number of alternative scientific and engineering possibilities, he does not choose among them on any systematic basis. Nevertheless, whether or not this function is carried out by converting organizations on a systematic basis or is even performed consciously, this choice is

nonetheless being made - even if it is by default. This is, of course, what happens when a conversion organization decides to pursue a particular set of scientific and engineering possibilities without according adequate consideration to available alternatives.

This step provides another instance of the model's highlighting an extremely important function in the processes of technological innovation which is often not carried out systematically or even consciously, and for which many conversion organizations do not have the necessary capabilities. Consideration of this function also illustrates the usefulness of the model in analyzing organizational interrelationships. For example, the model points up the fact that if the conversion organization carrying out this function is identical with the organization engaged in the research activity, certain problems are likely to arise. Consider the case of a corporation in which the director of a research facility is also responsible for searching the science and engineering communication system for alternative possibilities; and moreover is responsible for making the choice among those possibilities and the development implications of his own research effort,

as well as any possibilities arising from feedback from other development activities of the corporation. It would take an unusual individual in these circumstances not to be influenced by some biases in favor of possibilities emerging from the research activity under his direction. Clearly in a corporate situation in which there is a research facility, a development activity, and an information service searching for alternative S&E possibilities, choice among these possibilities should be exercised by an echelon of the organization above that of the laboratory director to preclude such bias in the decision making.

Step 20: In the light of its goals, C_d converts the selected scientific and engineering possibilities (with their associated estimates of required resources) into proposed programs, projects, or policies for submission to decision making agents in the socio-economic system; and Step 21: C_d transmits the proposed programs, projects, or policies to the decision making agents in the socio-economic system.

These particular steps in the conversion process are extremely important and crucial in almost all instances of technological innovation. In governmental

programs, one may think of an agency project monitor as a converter who (on the basis of the projects he is monitoring and other related work of which he is aware) prepares proposed programs, projects, or policies for approval by the top level of the agency, and perhaps for consideration by the Budget Bureau and approval by the Congress. In the situation of a large corporation, one can think of the converter as a vice president for research and development who prepares similar proposals for submission to top management and perhaps to the board of directors. The same function, however, is equally essential in situations involving individual inventors and entrepreneurs. If a group of engineers or scientists have come up with some promising new possibilities and have converted these technological possibilities into proposed plans (perhaps with the aid of some business-oriented associates), they must submit these plans to individuals or organizations in the socio-economic system in order to obtain necessary financial backing and support for their endeavor.

The first major problem that often occurs in the fulfillment of this function is that of identifying, selecting, or (when necessary) forming an organization

within the socio-economic system to which the proposals can be sent for appropriate action. This is, of course, particularly important with respect to individual inventors and engineers who may encounter extremely difficult problems in obtaining backing within the socio-economic system. It may be necessary for new groups to be formed within the socio-economic structure that can provide the required support, such as a syndicate of individual investors who put up the money for the proposed enterprise.

This particular problem is not normally present when the converting organization is part of the Government, since there is usually an established structure and procedures for preparing and submitting proposed plans. Even in the governmental system, however, this problem can sometimes be extremely important. For example, if various government officials serving as converters conclude that certain technological activities they have been supporting require much more extensive and sustained support than their particular mission provides for, there may not be an appropriate governmental group to which they can send their proposal. Their own

agency may not have wide enough responsibilities or mandate to consider this area in its broad context; and similarly no other Government agency may have the appropriate responsibilities to tackle the issues involved. Thus there may exist no focal point in the governmental structure to which these officials can direct their proposal for appropriate attention and action. In such cases, of course, they have to try to use various mechanisms, such as interagency committees and task forces and external advisory panels, to stimulate interest at higher levels in the possibility of establishing new structures within the government for coping with these problems.

After linking up with an appropriate organization (S_d) within the socio-economic structure, and after establishing effective relationships with S_d, there still remain a number of problems that are often involved in performing this function. One involves the impact of S_d on the way in which C_d must prepare and submit its proposed programs, projects, or policies. This problem is of considerable significance to government officials serving as converters who in the preparation of their proposed programs, projects, or

policies must take continuing account of the characteristics and requirements of their agency's top management, the Bureau of the Budget, and the Congress.

Another important problem involved in the performance of this function is the basic problem of how to convert science and engineering possibilities and associated estimates of resources required into proposed programs or projects pertinent to certain goals. The whole field of systems analysis is very much pertinent to this problem, and Planning-Programming-Budgeting-System now being applied in the Government is, in part, directed toward the systematic conversion of technological possibilities into proposed programs or projects. But although PPBS has proved effective in the Defense Department, it is still in its infancy with respect to non-defense governmental programs. Much of recent work on R&D management bears on the exercise of this function in the large corporate environment, but it is still performed in a most primitive manner throughout the socio-economic system as a whole. This is an extremely important problem that requires a great deal more research and insightful thinking before it is adequately resolved.

Step 22: In response to the various proposals that have been submitted (considering relevant goals and other applicable socio-economic factors), segments of the socio-economic system (S_d) make certain development resources available to a conversion organization (C_d).

The first major problem inherent in fulfillment of this function is the determination of the magnitudes and mix of specific resources to be provided. This problem is compounded by the fact that the resource determination decision with respect to a particular set of goals must generally be made as part of a wider allocation of resources among alternative goals. These decisions must take account of all applicable socio-economic factors including: market demands and opportunities, financial considerations, government policies and programs, political pressures, etc. Once these determinations have been made, there still remains what is often a difficult problem of obtaining the required resources. This is generally an important problem for almost all types of organizations. For example, it affects government agencies that may have to consider the level of scientific manpower resources available for certain projects they wish to support. It affects

large corporations that may have to be concerned with obtaining additional financing through bank loans or issues of debentures or common stock, or at the very least with assuring the most profitable use of their existing financial resources. And it certainly affects the smaller business firms and individual entrepreneurs who often encounter major problems in obtaining the necessary resources to carry out their proposed activities. Another problem that is often encountered in carrying out this function is deciding the extent to which the organization at the socio-economic level should allocate the resources it provides among the specific goals it imparts to the conversion organization, and the extent to which S_d should leave such allocation to C_d. To whatever extent S_d does engage in allocating resources to specific goals, there is often the corollary problem of what criteria and methods to employ in carrying out these allocations.

Step 23: C_d converts the goals that have been received from S_d into a form that can effectively guide the organization (A_d) which will carry out the development activity, and couples the goals with the resources that have been allocated.

As envisioned in the model, this function includes not only the actual conversion of the goals, but also their coupling with the allocated resources so that A_d will be in a position to direct specific resources toward particular goals. This problem is particularly important with respect to large-scale development activities, as in the defense and space programs, or broad social innovations in urban affairs, education, transportation systems, etc. The major problem in this area is that of delineating specific developmental objectives in the context of a coherent systems framework that takes realistic account of limitations on funds, time, available resources, etc., and at the same time, facilitates the effective accomplishment of the overall goals. A substantial portion of the effort in the whole field of systems management is directly concerned with coping with this problem. In the defense and space areas, detailed methodologies have been developed, extensive analyses have been undertaken, and a great deal of useful experience has been acquired with respect to this problem. In the emerging field of large-scale socio-economic innovations, where this problem is rapidly becoming

as perplexing as it is pressing and pervasive, there is still a great deal of work to be done before we can achieve even a minimum mastery of the systems management approach. Even after specific development objectives have been effectively delineated in a systems management framework, there remains the not negligible problem of expressing these objectives in a specific form which the development organization is capable of clearly comprehending. This is merely another manifestation of one of the recurrent themes of technological innovation: the underlying problem of translating goals and information from one level of a system, one link in a chain of activities, one set of professions and conceptions - to organizations and individuals at other levels, engaged in other activities, drawn from other professions, and with other perspectives and conceptions.

Step 24: The conversion organization (C_d) transmits specific development objectives, coupled with the resources to achieve those objectives, to the invention or development organization (A_d).

A major problem that may arise regarding fulfillment of this function is the identification, selection, or creation of an appropriate A_d to carry out the invention

or development activities. This is not a problem in a corporation with a single existing development facility that handles all development for the corporation, but it could be a problem with extremely large corporations that have several development facilities at their disposal and have to choose among them depending on the particular circumstances of the desired development. The problem would also be important in the case of an independent research firm that had decided to expand the scope of its activities by carrying some of its research output forward through the development stage; or in the case of individual research scientists who were embarking on a new enterprise that would include a development phase which they weren't capable of handling themselves. This problem is often present when the conversion organization lies within a government agency and the development activity is to be carried out under contract. All of the manifold problems of government contracting fall within this broad problem area. This problem with regard to selection of contractors on defense or space systems is not nearly so difficult as it is with regard to creating, or stimulating the

creation of, appropriate development organizations (A_d) to carry out various large-scale socio-economic innovations that the government has determined as desirable. Such innovations often entail development organizations with unusual combinations of interests, talents, and experience that are frequently not found in any existing business or non-profit organization or academic institution. The problem often becomes one of attempting to induce existing organizations to expand their own interests and capabilities so that they can carry out such developments effectively. Even after having identified, selected, or created an appropriate A_d, there remain the additional problems of establishing appropriate relationships with A_d, and of effectively transmitting the goals and resources.

Step 25: The development organization (A_d) searches existing sources of scientific and engineering knowledge to select out information relevant to its goals and within the limitations of available resources.

As indicated in the preceding chapter, this particular function may be performed many times by many individuals as an organization carries out its development activities. The kind of information sought

at one stage of the development may be quite different from what is sought at another stage. For example, at the start of a new development project, the kind of information sought usually pertains to the way in which the project should be organized and structured. Early in the course of the development, the information sought may concern major components that can be usefully incorporated, types of materials that may be used, significant new technological trends that one may be able to take advantage of, etc. Later on as the project proceeds, various decisions have been made which limit the options available to choose among alternatives of this sort. The remaining choices (important though they assuredly are) are usually restricted within much narrower confines, with the information requirements altered accordingly. At the conclusion of a project, the information sought may pertain to cost estimates, alternative verifications for various results, documentation for the report, etc. Thus there are many varieties of kinds of information that one may select out of the science and engineering communication system. The kinds of information will vary over the course of the project, and many cases

of selection will undoubtedly occur. This function is a continuing one over the course of most development projects.

In any event the major problems regarding fulfillment of this function are: the relationship of the development organization (A_d) to the communication system of science and engineering; the determination of criteria of relevance and methods of applying them in particular cases; and the enormous problem of locating and obtaining the relevant information within the communication system. These problems sound similar to those in Step 18 (and to the problems in Step 10 which are described in Chapter Four on the overall model). Although the statements of these problems sound similar, their manifestations in practice and what one would do to cope with them are quite different. In Step 18 one is searching for the development implications of substantive scientific and engineering knowledge. The problem of delineating criteria of relevance is quite different for such information from what it is for substantive knowledge per se. Similarly, the facts that different sorts of people are engaged in the search, and that the implications of substantive knowledge are located and stored differently in the system from

substantive knowledge itself alter the nature of the other problems involved in this function (namely, that of establishing appropriate relationships with the communication system, and that of locating and obtaining the relevant information).

In Step 10 (described in Chapter 4 below) research organizations search the science and engineering communication system for relevant information. The sort of information relevant to scientific research is generally, though by no means always, quite different from the sort of information relevant to development activity. In addition the location of such information in the communication system is quite different in both cases. For example, a great deal of science and engineering knowledge relevant to research is in the form of the professional journal literature; whereas much of the available information relevant to development is in the form of technical report literature. The problem of locating and obtaining information is considerably different in both of these cases.

This point should be borne in mind throughout the discussion of the model: Although the general problem statements will sometimes sound analogous for

similar functions in different parts of the model, the detailed manifestations of these problems, and the actions that might be recommended to cope with them are generally quite different for the various functions.

Step 26: Within the limitations of the resources that have been provided and making use of selected scientific and engineering knowledge, A_d carries out invention or development activities directed toward its objectives, which result in inventions, developed technology, and new problems and opportunities.

This step is obviously a complex combination of a great many sub-steps, involving a multitude of diverse functions. Exceedingly complex models could be - and in some cases have been - developed with the aim of accounting for these activities. In this model at its present stage of elaboration, we are merely concerned with the input of goals, resources, and information to this activity, and the resultant output of technological knowledge and the implications thereof. This model could, of course, be elaborated further in the future to delve into much greater detail in this step. In effect extensive sub-models could be 'plugged into' the overall model at this and at other

points. Short of doing that, we can nevertheless at this time indicate some of the major problem areas involved in carrying out this step. They include: the structure and organization of the development activity; its staffing; the maintenance of professional morale; the organization and direction of specific development projects, and coordination among them; the allocation of resources among projects; the flow of communication among the development staff, between the research and development groups, within the larger organizational context, and within the professional community; management controls over development activities; and subsequent evaluation of the development activities that have been carried out.

Steps 27 and 28: The development organization delineates the new technological capabilities, requirements, and problems resulting from its activities, and feeds back to the conversion organization the implications of this information with respect to further development.

The feedback of implications involved in this step should be clearly distinguished from the forward movement of information with respect to 'other engineering'

implications (described in Step 31 below). Implications regarding 'other engineering' refer to what is necessary to make the development an operational reality. The implications included in Step 28, however, refer to what additional development may be necessary to attain the original development goals (with whatever modifications they may have undergone in the interim); or to possible developments in other areas with respect to which this development activity has unintentionally uncovered significant information. The first problem with respect to Steps 27 and 28 is acceptance of the responsibility to carry out these functions. Development organizations are usually - and properly - oriented much more toward carrying out their development activities than they are toward delineating the results of those activities in a form communicable to the appropriate conversion organization. Even when this responsibility is accepted, there is often a problem of whether the development organization has the capability to carry out the function effectively. The specific task of delineating new technological capabilities and problems is a major problem in and of itself, involving such

questions as how does one identify, define, delimit, and appraise technological capabilities and assess associated problems. A major problem sometimes occurs in this area when the development organization is strongly committed to a particular line of development or a particular kind of technology, such as a technology which that same organization previously developed. When this is the case, the development organization may find it difficult to be entirely objective about the information it provides to its associated conversion organization. Thus there is a problem regarding the credibility of the information which is provided to the conversion organization. Oftentimes information regarding technological capabilities, requirements, and problems is based on estimates which can be colored by one's preconceptions. Sometimes the information is true as far as it goes, but may omit certain related information which could change the total picture if the conversion group were aware of it. (All of these factors should, of course, be taken into account by conversion organizations in structuring their relations with development groups and in assessing the information provided by such groups.)

This problem of delineating technological capabilities and problems occurs not only with respect to the objectives the development organization has been attempting to achieve, but also with respect to entirely different goals from the ones that have been imparted. This refers to the imaginative recognition of possibilities beyond the scope of what was under explicit consideration in the course of the development project. Successfully recognizing such implications for other areas entails an awareness of the problems, needs, and opportunities in other fields, and an alert imagination that can connect the results of a particular development effort with those diverse problems, needs, and opportunities. This is potentially an extremely important function which is not being carried out particularly extensively or well at the present time. Much more work needs to be done on ways of improving overall system performance of this function. Other important problems with regard to Steps 27 and 28 are those of: estimating the resources required to exploit new capabilities or tackle new problems; establishing effective relationships between the development and

conversion organizations; and preparing the new capabilities, requirements, and problems in an effective form for presentation to the conversion organization.

Step 29: The development organization (A_d) inputs the new knowledge into the technological-industrial communication system.

A major problem in this area is the extent to which new knowledge is entered into the communication system. At the left-hand side of the model (especially with regard to basic research), there is much greater entry of new knowledge into the science and engineering communication system. The technological-industrial communication system, however, does not receive the same free flow of information. This restriction on the flow of information occurs largely because many of the organizations engaged in invention or development are profit-seeking, and the new knowledge may have a potential profitability which they naturally wish to retain for themselves in so far as possible. The whole structure of the technological-industrial communication system has arisen with this point of view in mind. In addition there are, of course, the restrictions due to security -

classified information which constitute more of a problem for technology than for basic research information (where the relevance to practical matters of national security appears somewhat further removed). Even when information is entered into the technological-industrial communication system, it is often done so in a highly restricted way so that it is accessible only to very limited groups of users. To the extent that knowledge is entered into the system, there is the problem of identifying the appropriate target groups to which the information should be directed, as well as the problem of identifying, selecting, or creating appropriate channels through which the knowledge may be transmitted to these groups. There is also the problem of properly packaging the information prior to its input into the system. This problem of packaging is particularly important since the form of the package in which information is prepared determines to a large extent the portions of the overall system to which it can be provided, and hence its eventual retrievability.

Step 30: The new knowledge is incorporated into the body of technological knowledge.

Here again the major problem is the extent to which the new knowledge is available for such incorporation. To the extent that it is available, there is the major problem of how one conceptually relates the new knowledge to the existing store of knowledge. This function of conceptually relating the new knowledge is implemented by means of appropriate classification and identification (such as indexing). Another extremely important problem in this area is that of appraising the expected value of new knowledge. Most information systems currently focus on retrieving information that has some probability of being relevant, and do not accord adequate attention to the question of whether the information is of sufficient value to justify its retrieval. The appraisal of value is a function which is often not performed in the present system. Even when it is not consciously performed, however, it is being done by default. Even if all information in a system is considered equally valuable, this operating rule is in effect a form of implicit appraisal of the expected value of each element of information. Difficult though it may be to appraise the value of information, this is one challenge we must confront and resolve

if our information systems are to prove effective in the future. As the technological-industrial communication system becomes increasingly clogged with information, and it becomes more and more difficult to obtain relevant information within the system, it will become increasingly important to appraise the expected value of new knowledge; and on the basis of that appraisal, structure the manner in which the new knowledge is to be incorporated into the system for subsequent retrieval. Another major problem with respect to the exercise of this function is that of the systems and mechanisms employed in the actual processing of the information (an area of research that is commonly subsumed under the heading of 'information retrieval'). Another problem in this area is the extent to which and the means whereby the new knowledge is distributed within the overall communication system by methods such as selective dissemination.

Step 31: Development organization (A_d) transmits to conversion organization (C_e) the engineering implications of the new technological capabilities, requirements, and problems.

With this step we start what is essentially a new cycle of activity which we will not discuss in this chapter. We may merely point out that the transmission of these engineering implications of development to C_e triggers the cycle of 'other engineering' activity in the same way that this invention and development cycle was triggered by Step 16, which transmitted the development implications of new research knowledge.

This completes our discussion of the portion of the model which centers around invention and development activity. The reader should now be prepared to follow the description of the overall model presented in Chapter Four below.

CHAPTER FOUR

THE PROCESSES OF TECHNOLOGICAL INNOVATION

This chapter describes the overall systems model of the processes of technological innovation. Chart 10 below, The Processes of Technological Innovation, depicts the overall model. Following the chart each of the sixty-one steps or functions in the model is described, together with key problem areas that may be involved in fulfilling that function in practice. The problem areas as delineated are, of course, subject to appropriate additions, alterations, and refinements as further experience is acquired in the application of the model. (The symbols used for the institutional and organizational variables are those set forth in Chapter Three, pages 79 and 80.)

THE PROCESSES OF TECHNOLOGICAL INNOVATION

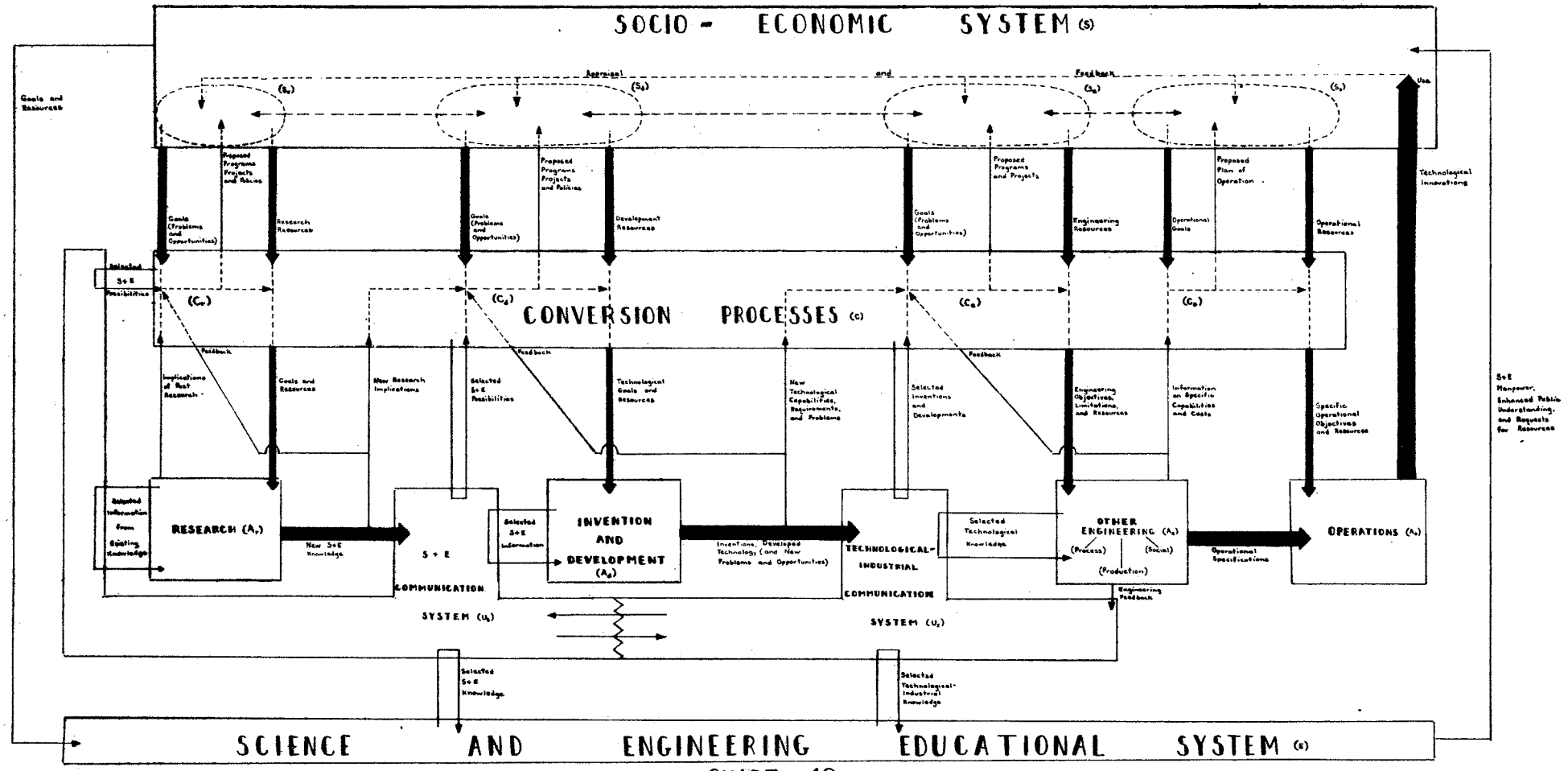


CHART 10

1. A_r TRANSMITS THE IMPLICATIONS OF PAST RESEARCH TO C_r.

   a. Acceptance of the responsibility to carry out this function.
   b. Perception of the research implications of substantive scientific and engineering knowledge.
   c. Estimating the resources required to pursue particular implications.
   d. Relationship of the research organization (A_r) to a decision making organization (C_r) that can carry out the required conversion processes (3, 4, 5, 6).
   e. Preparation of the implications and estimated resources required in an effective form for presentation to C_r.
   f. Actual communication of the possibilities and resource estimates to C_r.

2. S_r TRANSMITS GOALS FOR RESEARCH TO C_r.

   a. Existence within the socio-economic system of an appropriate S_r capable of carrying out this function effectively.

b. Determination of the goals (including problems, opportunities, limitations, objectives, etc.) taking into account applicable socio-economic factors such as national policies and problems, financial constraints, etc.

c. Priority ordering among goals.

d. Whether to stimulate and/or support research relevant to those goals.

e. Identification and selection or creation of an appropriate C_r to carry out the required conversion processes (3, 4, 5, 6).

f. Establishment of the appropriate relationships between S_r and C_r.

g. Specific formulation of the goals.

h. Actual transmission of the goals to C_r.

3. C_r SEARCHES EXISTING SOURCES OF KNOWLEDGE TO SELECT OUT OTHER SCIENCE AND ENGINEERING POSSIBILITIES RELEVANT TO THE GOALS.

a. Recognition of the importance of carrying out this function.

b. Relationship of C_r to the communication system of science and engineering (U_s).

c. Determination of criteria of relevance and methods for applying them to particular cases.

d. Locating and obtaining the relevant information.

4. C_r SELECTS SPECIFIC SCIENTIFIC AND ENGINEERING POSSIBILITIES THAT SHOULD BE PURSUED.

   a. Appraising alternative scientific and engineering possibilities relevant to the goals, and choosing among them.

5. IN LIGHT OF THE GOALS WITH WHICH IT HAS BEEN PROVIDED, C_r CONVERTS THE SELECTED SCIENTIFIC AND ENGINEERING POSSIBILITIES AND ESTIMATED RESOURCES REQUIRED INTO PROPOSED PROGRAMS, PROJECTS, OR POLICIES FOR SUBMISSION TO S_r.

   and

6. C_r TRANSMITS THE PROPOSED PROGRAMS, PROJECTS, OR POLICIES TO S_r.

   a. How to carry out the conversion of the scientific and engineering possibilities and resource estimates into proposed programs, projects, or policies relative to the goals.

b. Effects of S_r's characteristics and its relationship to C_r on the way in which proposed programs or projects have to be prepared and submitted by C_r.

c. Actual communication of proposed programs, projects, or policies to S_r.

7. S_r PROVIDES RESEARCH RESOURCES TO C_r.

a. Identification and selection or creation of the appropriate C_r to carry out the required conversion processes (8, 9).

b. Establishment of the appropriate relationships between S_r and C_r.

c. Determination of magnitudes and mix of resources to be provided.

d. Obtaining the resources.

e. Extent to which S_r allocates the resources among specific goals; extent to which this function is left to C_r.

f. To the extent that S_r does allocate the resources, the criteria and methods for doing so.

g. Actual transmission of resources.

8. C_r CONVERTS THE GOALS RECEIVED FROM S_r INTO A FORM COMMUNICABLE TO A_r, AND COUPLES THE GOALS WITH THE RESOURCES THAT HAVE BEEN PROVIDED.

   a. How to carry out this conversion in such a way that the converted goals can influence the direction of A_r's efforts without unduly inhibiting the creativity of A_r's research activity. (In the case of basic research, goals generally are not imposed with respect to the substance of research activity, but rather with respect to associated conditions such as an environment conducive to creative work.)

   b. Extent to which and methods whereby C_r allocates overall resources among component goals.

9. C_r TRANSMITS THE GOALS AND RESEARCH RESOURCES TO A_r.

   a. Identifying, selecting, inducing, or creating an appropriate A_r to carry out the research activities.

   b. Establishment of the appropriate relationships between C_r and A_r.

   c. Effective transmission of the goals and resources.

10. A_r SEARCHES EXISTING SOURCES OF SCIENTIFIC AND ENGINEERING KNOWLEDGE TO SELECT OUT THAT INFORMATION RELEVANT TO THE GOALS AND WITHIN THE LIMITATION OF AVAILABLE RESOURCES.

    a. Relationship of A_r to the communication system of science and engineering (U_S).
    b. Determination of criteria of relevance and methods of applying them to particular cases.
    c. Locating and obtaining the relevant information.

11. IN LIGHT OF SUCH GOALS AS MAY BE GIVEN, WITHIN THE LIMITATIONS OF AVAILABLE RESOURCES, AND MAKING USE OF SELECTED SCIENTIFIC AND ENGINEERING KNOWLEDGE, A_r CARRIES OUT RESEARCH WHICH CREATES NEW KNOWLEDGE.

    a. Structure and organization of A_r.
    b. Staffing.
    c. Creation and maintenance of effective research environment and morale among staff.
    d. Organization and direction of particular research projects.
    e. Allocation of resources among projects.

f. Flow of communication among staff, within larger organizational context, and within wider professional communities.

g. Management controls over research activities.

h. Appraisal of research performance.

12. A_r RECOGNIZES THE IMPLICATIONS OF NEW SCIENTIFIC AND ENGINEERING KNOWLEDGE

and

13. A_r FEEDS BACK TO C_r THE IMPLICATIONS OF NEW KNOWLEDGE WITH RESPECT TO FURTHER RESEARCH.

a. Acceptance of the responsibility to carry out these functions.

b. Capability of A_r to carry out functions effectively.

c. How to recognize the implications of the new knowledge with respect to the original goals.

d. How to recognize the implications of the new knowledge with respect to other goals beyond the scope of the project.

e. Estimating the resources required to pursue particular implications.

f. Relationship of A_r to C_r.

g. Preparation of the implications and estimated resources required in an effective form for presentation to C_r.

h. Actual feedback of the information to C_r.

14. A_r TRANSMITS THE NEW KNOWLEDGE INTO THE SCIENCE AND ENGINEERING COMMUNICATION SYSTEM.

a. Acceptance of the responsibility to perform this function.

b. Identification of appropriate target groups to which the information should be directed.

c. Identification, selection or creation of appropriate channels through which the knowledge may be transmitted (such as a particular journal in which it might be published).

d. Packaging of the information prior to input into system (e.g., writing of a scientific paper).

e. Actual transmission of the new knowledge.

15. THE NEW KNOWLEDGE IS INCORPORATED INTO THE TOTAL BODY OF SCIENTIFIC AND ENGINEERING KNOWLEDGE.

a. Extent to which this function is performed.

b. Conceptually relating the new knowledge to the existing stroe of knowledge, by appropriate classification and identification (e.g., indexing).

c. Appraising the expected value of the new knowledge.

d. Processing the new information to place it in the desired relationships to existing knowledge.

e. The extent to which, and means whereby, the new knowledge is distributed within the overall communication system (e.g., selective dissemination): To what target groups, through what channels, and in what form.

f. The storage of the knowledge in such form that it can later be retrieved when it appears of sufficient relevance and value.

16. A_r TRANSMITS TO C_d THE DEVELOPMENT IMPLICATIONS OF NEW RESEARCH KNOWLEDGE.

a. Acceptance of the responsibility to carry out this function.

b. Capability of discerning the development implications of new research knowledge.

c. Identifying, selecting, inducing or creating an appropriate C_d to carry out the required conversion processes (18, 19, 20, 21).

d. Establishment of the appropriate relationship with C_d.

e. Estimating the resources required to pursue particular developments.

f. Preparation of the implications and required resources in an effective form for presentation to C_d.

g. Actual communication of the implications and resource estimates to C_d.

17. S_d TRANSMITS GOALS FOR DEVELOPMENT TO C_d.

a. Determination of goals (including problems, opportunities, objectives, limitations) taking full account of applicable socio-economic considerations (e.g., market appraisals, legal problems, political pressures, financial constraints, public opinion, etc.).

b. Priority ordering among goals.

c. Whether to foster and/or support development and invention activities directed toward those goals.

d. Identification, selection or creation of appropriate C_d to carry out the required conversion processes (18, 19, 20, 21).

e. Establishment of the appropriate relationships between S_d and C_d.

f. Specific formulation of the goals.

g. Actual transmission of the goals to C_d.

18. C_d SEARCHES THE S&E COMMUNICATION SYSTEM IN ORDER TO SELECT VARIOUS SCIENTIFIC AND ENGINEERING POSSIBILITIES PERTINENT TO ITS GOALS.

a. Recognition of the importance of performing this function.

b. Relationship of C_d to the communication system of science and engineering (U_s).

c. Determination of criteria of relevance and methods for applying them in particular cases.

d. Locating and obtaining the relevant information.

19. C_d SELECTS FROM RELEVANT SCIENCE AND ENGINEERING POSSIBILITIES SPECIFIC POSSIBILITIES TO BE PURSUED.

a. Appraising alternative scientific and engineering possibilities pertinent to the goals, and choosing among them.

20. IN LIGHT OF ITS GOALS, C_d CONVERTS THE SELECTED SCIENTIFIC AND ENGINEERING POSSIBILITIES AND ESTIMATES OF REQUIRED RESOURCES INTO PROPOSED PROGRAMS, PROJECTS, OR POLICIES FOR SUBMISSION TO S_d.

and

21. C_d TRANSMITS THE PROPOSED PROGRAMS, PROJECTS, OR POLICIES TO S_d.

a. Identification, selection, or formation of an appropriate S_d.
b. Establishment of the appropriate relationships between C_d and S_d.
c. Effects of S_d's characteristics and its relationship to C_d on the way in which proposed programs, projects, or policies have to be prepared and submitted by C_d.
d. How to convert the scientific and engineering possibilities and resource estimates into proposed programs, projects, or policies

pertinent to the goals.

e. Actual communication of the proposed programs, projects, or policies to S_d.

22. IN RESPONSE TO THE PROPOSALS THAT HAVE BEEN SUBMITTED (CONSIDERED IN THE LIGHT OF THE GOALS AND APPLICABLE SOCIO-ECONOMIC FACTORS) S_d MAKES CERTAIN DEVELOPMENT RESOURCES AVAILABLE TO C_d.

a. Identifying, selecting, inducing or creating the appropriate C_d to carry out the required conversion processes (23, 24).

b. Establishment of the appropriate relationships between S_d and C_d.

c. Determination of magnitudes and mix of resources to be provided.

d. Obtaining the resources.

e. Extent to which S_d allocates the resources among the specific goals; extent to which this function is left to C_d.

f. To the extent that S_d does allocate the resources, the criteria and methods for doing so.

g. Provision of the resources.

23. C_d CONVERTS THE GOALS RECEIVED FROM S_d INTO AN EFFECTIVE FORM FOR PRESENTATION TO A_d, AND COUPLES THE GOALS WITH THE RESOURCES THAT HAVE BEEN PROVIDED.

a. How to convert the more general goals into specific development objectives that can guide A_d's activities.

b. Allocation of the overall resources among the specific development objectives.

c. Development of a comprehensive systems plan which takes realistic account of relevant limitations of time, funds, manpower resources, etc., and which facilitates achievement of the specific development objectives.

d. Preparation in an effective form for presentation to A_d.

24. C_d TRANSMITS SPECIFIC DEVELOPMENT OBJECTIVES, COUPLED WITH RELATED RESOURCES, TO A_d.

a. Identification and selection or creation of an appropriate A_d to carry out the development activities.

b. Establishment of the appropriate relationships between C_d and A_d.

c. Effective transmission of the goals and resources.

25. A_d SEARCHES EXISTING SOURCES OF SCIENTIFIC AND ENGINEERING KNOWLEDGE TO SELECT OUT THAT INFORMATION RELEVANT TO THE GOALS AND WITHIN THE LIMITATIONS OF AVAILABLE RESOURCES.

a. Relationship of A_d to the communication system of science and engineering (U_s).
b. Determination of criteria of relevance and methods of applying them in particular cases.
c. Locating and obtaining the relevant information.

26. WITHIN THE LIMITATIONS OF RESOURCES PROVIDED, AND MAKING USE OF SELECTED SCIENTIFIC AND ENGINEERING KNOWLEDGE, A_d CARRIES OUT THE INVENTION OR DEVELOPMENT ACTIVITIES DIRECTED TOWARD ITS OBJECTIVES: RESULTING IN INVENTIONS, DEVELOPED TECHNOLOGY, AND NEW PROBLEMS AND OPPORTUNITIES.

a. Structure and organization of A_d.
b. Staffing.
c. Maintenance of professional morale.

d. Organization and direction of specific development projects, and coordination among them.

e. Allocation of resources among the projects.

f. Flow of communications among development staff, between research and development groups, within larger organizational context and within wider professional communities.

g. Management controls over development activities.

h. Evaluation of development activities.

27. A_d DELINEATES THE NEW TECHNOLOGICAL CAPABILITIES, REQUIREMENTS, AND PROBLEMS RESULTING FROM THE INVENTION AND DEVELOPMENT ACTIVITIES.

and

28. A_d FEEDS BACK TO C_d THE IMPLICATIONS OF THIS INFORMATION WITH RESPECT TO FURTHER DEVELOPMENT.

a. Acceptance of the responsibility to carry out this function.

b. Capability of A_d to carry out this function objectively.

c. How to recognize and delineate new technological capabilities and problems with respect to the original goals.

d. How to recognize and delineate new technological capabilities and problems with respect to other goals beyond the scope of the project.

e. Estimating the resources required to exploit new capabilities or tackle new problems.

f. Relationship of A_d to C_d.

g. Preparation of the new capabilities, requirements, and problems in an effective form for presentation to C_d.

h. Actual feedback of the information to C_d.

29. A_d INPUTS THE NEW KNOWLEDGE INTO THE TECHNOLOGICAL-INDUSTRIAL COMMUNICATION SYSTEM.

a. Extent to which new knowledge is entered into the system.

b. Identification of appropriate target groups to which the information should be directed.

c. Identification, selection, or creation of appropriate channels through which the knowledge may be transmitted.

d. Packaging of the information prior to its input into system.

e. Actual transmission of the new knowledge.

30. THE NEW KNOWLEDGE IS INCORPORATED INTO THE BODY OF TECHNOLOGICAL KNOWLEDGE.

a. Extent to which new knowledge is available for such incorporation.

b. Conceptually relating the new knowledge to the existing store of knowledge, by appropriate classification and identification (e.g., indexing).

c. Appraising the expected value of the new knowledge.

d. Processing the new knowledge to place it in the desired relationship to existing knowledge.

e. The extent to which, and means whereby, the new knowledge is distributed within the overall communication system (e.g., selective dissemination): to what target groups, through what channels and in what form.

f. The storage of the knowledge in such form that it can later be retrieved when it appears of sufficient relevance and value.

31. A_d TRANSMITS TO C_e THE ENGINEERING IMPLICATIONS OF NEW TECHNOLOGICAL CAPABILITIES, REQUIREMENTS AND PROBLEMS.

a. Acceptance of the responsibility to carry out this function.

b. Identifying, selecting, inducing or creating an appropriate C_e to carry out the required conversion processes (33, 34, 35, 36).

c. Establishment of the appropriate relationship between A_d and C_e.

d. Preparation of the implications and estimated resources required in an effective form for presentation to C_e.

e. Actual communication of the implications and resource estimates to C_e.

32. S_e TRANSMITS GOALS FOR ENGINEERING TO C_e.

a. Determination of goals (including problems, opportunities, objectives, limitations) taking full account of applicable socio-economic considerations (e.g., market appraisals, legal problems, political pressures, financial constraints, public opinion, etc.).

b. Priority ordering among goals.

c. Whether to undertake engineering activity directed toward those goals.

d. Identification, selection or creation of an appropriate C_e to carry out the required conversion processes (33, 34, 35, 36).

e. Establishment of the appropriate relationships between S_e and C_e.

f. Specific formulation of the goals.

g. Actual transmission of goals to C_e.

33. C_e SEARCHES ACCESSIBLE SEGMENTS OF THE TECHNOLOGICAL-INDUSTRIAL COMMUNICATION SYSTEM TO SELECT ALTERNATIVE TECHNOLOGICAL POSSIBILITIES PERTINENT TO ITS GOALS.

a. Relationship of C_e to the technological-industrial communication system (U_I).

b. Determination of criteria of relevance and methods for applying them to particular cases.

c. Locating and obtaining the relevant information.

34. C_e SELECTS SPECIFIC INVENTIONS AND DEVELOPMENTS FOR FURTHER ENGINEERING ACTIVITY.

a. Appraising alternative technological possibilities pertinent to the goals, and choosing among them.

35. C_e CONVERTS THE INFORMATION REGARDING SPECIFIC TECHNOLOGICAL INVENTIONS AND DEVELOPMENTS INTO PROPOSED ENGINEERING PROGRAMS OR PROJECTS, DESIGNED TO MEET THE GOALS.

and

36. C_e TRANSMITS PROPOSED ENGINEERING PROGRAMS OR PROJECTS TO S_e.

a. Identification, selection, or formation of an appropriate S_e.
b. Establishment of the appropriate relationships between C_e and S_e.
c. Effects of S_e's characteristics and its relationship to C_e on the way in which proposed programs or projects have to be prepared and submitted by C_e.

d. How to convert the information regarding technological developments and inventions into proposed programs or projects.

e. Actual communication of proposed programs and projects to S_e.

37. S_e MAKES ENGINEERING RESOURCES AVAILABLE TO C_e.

a. Identifying, selecting, inducing or creating the appropriate C_e to carry out the required conversion processes (38, 39).

b. Establishment of the appropriate relationships between S_e and C_e.

c. Determination of magnitudes and mix of resources to be provided.

d. Obtaining the resources.

e. Extent to which S_e allocates the resources among specific goals; extent to which this function is left to C_e.

f. To the extent S_e does allocate, the criteria and methods for doing so.

g. Actual transmission of resources.

38. C_e CONVERTS THE GOALS RECEIVED FROM S_e INTO AN EFFECTIVE FORM FOR PRESENTATION TO A_e, AND COUPLES THEM WITH THE RESOURCES THAT HAVE BEEN PROVIDED.

a. How to convert the more general goals into precise engineering objectives that can guide A_e's activities.
b. Allocation of the overall resources among the precise engineering objectives.
c. Development of a comprehensive systems plan which takes realistic account of relevant limitations, including any pre-established operational parameters; and which facilitates achievement of the precise engineering objectives.
d. Preparation in an effective form for presentation to A_e.

39. C_e TRANSMITS SPECIFIC ENGINEERING OBJECTIVES, LIMITATIONS AND RESOURCES TO A_e.

a. Identification, selection or creation of an appropriate A_e to carry out the engineering activities.
b. Establishment of the appropriate relationships between C_e and A_e.
d. Effective transmission of goals and resources.

40. A_e SEARCHES ACCESSIBLE SOURCES OF TECHNOLOGICAL KNOWLEDGE TO SELECT OUT THAT INFORMATION PERTINENT TO ITS ENGINEERING OBJECTIVES WITHIN THE CONTEXT OF THE ESTABLISHED LIMITATIONS.

a. Relationship of A_e to the technological-industrial communication system.
b. Delineation of criteria of relevance and methods of applying them in particular cases.
c. Locating and obtaining the relevant information.

41. WITHIN THE LIMITATIONS IMPOSED, AND MAKING USE OF SELECTED TECHNOLOGICAL KNOWLEDGE, A_e ENGAGES IN ENGINEERING ACTIVITY TO MEET THE SPECIFIC OBJECTIVES AND TO GENERATE THE REQUISITE OPERATIONAL SPECIFICATIONS.

a. Structure and organization of A_e.
b. Staffing.
c. Maintenance of professional morale.
d. Organization and direction of specific engineering projects, and coordination among them.
e. Allocation of resources among the projects.

f. Flow of communication among engineering staff, between development and engineering groups, within larger organizational context, and within wider professional communities.

g. Management controls over engineering activities.

h. Evaluation of engineering activities.

42. A_e ELICITS AND COMPILES INFORMATION ON THE CAPABILITIES, COSTS, AND PROBLEMS ASSOCIATED WITH THE DESIRED INNOVATION.

and

43. A_e FEEDS BACK TO C_e THE IMPLICATIONS OF THIS INFORMATION WITH RESPECT TO ADDITIONAL ENGINEERING.

a. Capability of A_e to carry out this function effectively.

b. How to formulate information regarding specific capabilities, costs and problems associated with the innovation.

c. How to recognize and formulate the information concerning other important engineering problems and possibilities encountered in the course of the activity.

d. Relationship of A_e to C_e.

e. Actual feedback of information to C_e.

44. A_e TRANSMITS THE OPERATIONAL SPECIFICATIONS TO A_o.

a. Preparation of the engineering results in a sufficiently comprehensible, complete, and precise form to provide an effective framework for operations.

b. Actual communication of the information to A_o.

45. A_e MAY PROVIDE SOME ENGINEERING FEEDBACK INTO THE TECHNOLOGICAL-INDUSTRIAL COMMUNICATION SYSTEM.

a. Extent to which this function is performed and new engineering knowledge is entered into the system.

b. Identification of appropriate target groups to which the information should be directed.

c. Choice of channels through which the knowledge is transmitted.

d. Packaging of the information prior to its input into the system.

e. Actual transmission of the new knowledge.

46. A_e TRANSMITS INFORMATION ON THE SPECIFIC CAPABILITIES AND COSTS OF THE INNOVATION TO C_o.

a. Identifying, selecting, inducing or creating an appropriate C_o to carry out the required conversion processes (48, 49, 50, 51).

b. Establishment of the appropriate relationship between A_e and C_o.

c. Preparation of the information in an effective form for presentation to C_o.

d. Actual communication of the information to C_o.

47. S_o TRANSMITS OPERATIONAL GOALS TO C_o.

a. Determination of goals (including problems, opportunities, objectives, limitations) taking full account of applicable socio-economic considerations (e.g., market appraisals, legal problems, political pressures, financial constraints, public opinion, etc.).

b. Ordering of goals.

c. Whether to undertake operational activity aimed at these goals.

d. Identification, selection or creation of an appropriate C_o to prepare proposed plans of operation.

e. Establishment of the appropriate relationships between S_o and C_o.

f. Specific formulation of the goals.

g. Actual transmission of goals to C_o.

48. C_o UTILIZES THE INFORMATION ON SPECIFIC CAPABILITIES AND COSTS TO PREPARE PROPOSED OPERATIONAL PLANS TO MEET THE OPERATIONAL GOALS.

and

49. C_o TRANSMITS THE PROPOSED OPERATIONAL PLANS TO S_o.

a. Identification, selection, or formation of an appropriate S_o.

b. Establishment of the appropriate relationships between C_o and S_o.

c. Effects of S_o's characteristics and its relationship to C_o on the way in which proposed programs or projects have to be prepared and submitted by C_o.

d. How to convert the information into proposed plans that meet the goals.

e. Actual communication of proposed plans to S_o.

50. S_o MAKES OPERATIONAL RESOURCES AVAILABLE TO C_o.

a. Identifying, selecting, inducing or creating the appropriate C_o to carry out the required conversion processes (51, 52).

b. Establishment of the appropriate relationships between S_o and C_o.

c. Determination of the specific resources to be provided.

d. Obtaining the resources.

e. Actual transmission of the resources.

51. C_o CONVERTS THE GOALS RECEIVED FROM S_o INTO AN EFFECTIVE FORM FOR PRESENTATION TO A_o, AND COUPLES THEM PRECISELY WITH THE RESOURCES THAT HAVE BEEN PROVIDED.

a. Delineation of specific operational objectives (including relevant limitations) in a sufficiently comprehensible, complete and precise form to direct A_o's operations effectively (including precise coupling of objectives and resources).

b. Determination of the specific segments of the socio-economic system into which the innovation will be introduced.

c. Identification, selection or creation of the appropriate channels and/or institutional arrangements through which the innovation will be introduced.

d. Determination of the time and magnitude parameters of the innovation, such as: volume and rate of output, distribution schedule, etc.

52. C_o TRANSMITS SPECIFIC OPERATIONAL OBJECTIVES AND RESOURCES TO A_o.

a. Identification, selection or creation of an appropriate A_o to conduct the operations.

b. Establishment of the appropriate relationships between C_o and A_o.

c. Effective transmission of objectives and resources.

53. A_o PRODUCES THE TECHNOLOGICAL INNOVATION.

a. Full range of administrative problems normally involved in instituting a new technology-based operation, or in substantially altering such an existing operation.

54. A_o INTRODUCES THE INNOVATION INTO THE SOCIO-ECONOMIC SYSTEM.

a. "Packaging" the innovation so as to facilitate its introduction and its acceptance by the socio-economic system.

b. Transmitting the innovation effectively.

55. SEGMENTS OF THE SOCIO-ECONOMIC SYSTEM (S_u) MAKE USE OF THE TECHNOLOGICAL INNOVATION; AND VARIOUS INSTITUTIONS, ORGANIZATIONS, GROUPS, AND INDIVIDUALS (S_p) APPRAISE ITS EFFECTIVENESS AND VALUE.

a. Existence or establishment of appropriate institutions, organizations, groups, or individuals who will assume responsibility for making such appraisals in particular cases.

b. Their relationship to the segments of the socio-economic system making use of the technological innovation (i.e., the relationship of S_p to S_u).

c. The relationship of S_p to the operational activity (A_o) responsible for introducing the innovation into the socio-economic system.

d. The capability of S_p to make such appraisals effectively and objectively.

e. The extent to which the full range of relevant interests and pertinent factors are taken into account in the appraisals (including consideration of social, cultural, and human values, as well as all pertinent economic factors).

f. The specific mechanisms, methodologies, and techniques for making such appraisals, and for attempting to cope with conflicting appraisals.

g. The timeliness of appraisals.

56. S_p FEEDSBACK THE RESULTS OF ITS APPRAISALS TO THOSE SEGMENTS OF THE SOCIO-ECONOMIC SYSTEM ENGAGED IN THE DETERMINATION OF RELEVANT GOALS AND THE ALLOCATION OF RELATED RESOURCES (S_r, S_d, S_e, S_o).

a. Acceptance of the responsibility to carry out this function.

b. Identification, selection, or formation of appropriate S_r, S_d, S_e, or S_o which can receive and act on such appraisals.

c. Establishment of effective relationships between S_p and S_r, S_d, S_e, or S_o.

d. Preparation of the appraisal in an effective form for transmission to S_r, S_d, S_e, or S_o.

e. Actual transmission of the appraisal.

57. THE SOCIO-ECONOMIC SYSTEM PROVIDES GOALS AND RESOURCES TO THE SCIENCE AND ENGINEERING EDUCATIONAL SYSTEM.

a. Determination of goals.

b. Priority ordering of goals.

c. Whether to stimulate and/or support education relevant to those goals.

d. Determination of magnitudes and mix of resources to be provided.

e. Obtaining the resources.

f. Extent to which S allocates resources among goals, the extent to which this function is left to E.

g. To the extent that S does allocate resources, the criteria and methods for doing so.

h. Specific formulation of the goals so as to influence the direction of E's efforts without unduly inhibiting the effectiveness of E's educational activities.

i. Effective transmission of goals and resources.

58. E SELECTS SCIENTIFIC AND ENGINEERING INFORMATION THAT IS UP-TO-DATE, SIGNIFICANT AND SUITABLE TO ITS EDUCATIONAL OBJECTIVES.

and

59. E SELECTS TECHNOLOGICAL-INDUSTRIAL INFORMATION THAT IS UP-TO-DATE, SIGNIFICANT AND SUITABLE TO ITS EDUCATIONAL OBJECTIVES.

a. Relationships of E to the scientific-technological industrial communication systems (including consideration of the extent to which function 59 is performed in practice).

b. Determination of criteria of significance and suitability, and methods of applying them in particular situations.

c. Locating and obtaining up-to-date information that meets these criteria.

60. IN LIGHT OF THE GOALS AND WITHIN THE LIMITATIONS OF ITS RESOURCES, E MAKES USE OF SELECTED SCIENTIFIC-TECHNOLOGICAL - INDUSTRIAL KNOWLEDGE TO GENERATE TRAINED SCIENTIFIC AND ENGINEERING MANPOWER AND ENHANCED PUBLIC UNDERSTANDING OF SCIENCE AND TECHNOLOGY (WHILE DELINEATING REQUIREMENTS FOR ADDITIONAL RESOURCES).

and

61. E PROVIDES THE SOCIO-ECONOMIC SYSTEM WITH S&E MANPOWER, ENHANCED PUBLIC UNDERSTANDING OF SCIENCE AND TECHNOLOGY, AND REQUIREMENTS FOR ADDITIONAL RESOURCES.

a. Structure and organization of E
   (1) overall
   (2) for specific segments of the educational system
   (3) for particular educational institutions
b. Obtaining and training sufficient numbers of teachers and educational administrators.
c. Management of educational institutions, including the critical problem of creating and maintaining an effective educational environment.

d. Converting the general goals transmitted by society into operational goals specific to educational processes.

e. Developing alternative curricula and educational methodologies and adopting or adapting them in specific situations.

f. Allocating resources among specific segments of the system and to particular institutions.

g. Evaluating educational activities.

h. Accepting the responsibility to engage in activities intended to enhance public understanding of science and technology, and developing the capability to perform this function effectively.

i. Preparing proposed educational programs.

j. Estimating the resources required to carry out particular programs.

k. Effectively preparing and transmitting requests for additional resources to the socio-economic system.

CHAPTER FIVE

SYSTEM CHARACTERISTICS, SIGNIFICANCE, AND USES

This chapter considers the overall characteristics of the systems model set forth in the preceding portions of the report, discusses its general significance, and examines the uses to which it can be put.

A - System Characteristics

Let us consider the general characteristics of technological innovation as exemplified in the model (depicted in Chart 10 on page 124). As we move across the chart from left to right, the scope and character of the goals provided by the socio-economic system change significantly. The goals are much more general at the far left, and become increasingly specific as we move across the model. Research goals, for example, may refer to a broad interdisciplinary field requiring concerted exploration such as oceanography; or to a major health problem which needs to be better understood such as cancer. Operational goals, in contrast, may refer to a specific segment of a market which the top management of a firm wishes to capture with a new technological product; or for example, to the

time period in which water pollution is to be eradicated in a particular body of water. It should also be noted that the goals come to exert much more control over the direction of technological activities as one moves across the chart from left to right. Thus socio-economic goals exert very little influence over the course of research projects, as compared to the large degree of control exercised over the conduct of operational activities.

The resources provided by the socio-economic system exhibit a similar set of changes. As we move across the model from left to right, the resources generally become greater and greater in magnitude. Of course accelerators for research in high energy physics are certainly not cheap. For the most part, however, the financial resources required for research are less than those needed for development, which in turn are less than those for engineering and operations respectively. Manpower resources similarly increase in numbers of personnel required as we move across the model; although scarcity of specialized skills is generally greatest at the research end of the system, and diminishes as we move across to operations.

The scope and significance of the information moving upward from the activity spectrum also change as we traverse the model. The implications of substantive scientific knowledge shown at the left-hand side of the chart usually encompass a wide band of possibilities. This band narrows progressively as we move across the chart so that the information on specific capabilities and costs emerging from the engineering activity generally circumscribes a fairly narrow range of possibilities. At the same time the short-run significance or immediacy of the implications is usually slight at the far left, and increases substantially as we move across the chart to the engineering activity which may generate implications of almost immediate significance to the socio-economic system. (Of course, the long-run significance of implications at the research end of the spectrum may be extremely great.)

Similarly the extent and strength of coupling goals and resources in the conversion segment varies across the model. The coupling of goals and resources for basic research, for example, is generally far less extensive and far more flexible than the precise, detailed coupling of operational goals and resources at the far right of the model. In the present

sociological system of science and technology, the prime measures of research success are the soundness and significance of the results achieved, with but very little attempt - if any - to relate the value of the results to the investment necessary to accomplish them. (This last factor will undoubtedly increase in importance as the socio-economic system continues to restrict the proportion of its total resources available for research and development, while scientific and engineering possibilities continue to proliferate exponentially.) In most operational activities, on the other hand, cost factors are extremely important, if not paramount. Hence, it is essential that the resources provided be coupled precisely to the operational objectives in order to increase efficiency and minimize cost.

Obviously the nature of technological activities also varies as the model is traversed. For example, the underlying conflict between creativity and control changes its character as we move from left to right. In basic research, creativity is clearly of maximum importance, and administrative control is often treated as a necessary evil. In the operational activity, on the other hand, administrative control

is paramount, and creativity is usually relegated to public relations releases about the firm. The changing character of this conflict as we move across the spectrum clearly has a major impact on the structure, organization, and conduct of activities within the major technological modes.

The character of the communication system also changes as we move across the model. Communication is usually much more fluid and free-flowing in the basic research area and becomes progressively more rigid and restricted as we move into the technological-industrial communication system. Thus it is generally more difficult for the engineer in industry to locate, obtain, and sift relevant information of value than it is for the scientist engaged in basic research, who is frequently in personal communication with other members of the elite 'invisible college' of experts in his area. The relationship of the educational system to the processes of technological innovation also seems to vary as we move across the system: with educational programs apparently much better coupled to communication in basic science than in applied science or technology.

To facilitate comprehension of the overall systems model, we may conceive of it as a vast pumping system. We see the goals of the socio-economic system interacting, in the context of the conversion segment, with the implications of substantive scientific and technological knowledge. This interaction results in proposed programs, projects, or policies which trigger the release of resources from the socio-economic system. These resources and the goals are converted and coupled together in the conversion segment and pumped into the activity spectrum. The input of the coupled goals and resources into the activity spectrum provides the fuel or propulsive force for the creation of new substantive knowledge. The substantive knowledge is pumped across the activity spectrum through the medium of the communication systems, which can be conceived of as consisting of interconnected reservoirs of knowledge (from which the organizations engaged in technological activity select information relevant to their goals and within the limitations of their resources). The end result of these transformations is technological knowledge in the form of precise operational specifications which interact in the context of the operational activity with the operational objectives

and resources to produce the technological innovation. The innovation is introduced into the socio-economic system, where it is used and appraised; and the results fedback to affect the subsequent selection and determination of goals, and the acquisition and allocation of related resources. Concurrent with these processes, the educational system is continually siphoning off selected substantive knowledge for use in generating new scientific and engineering manpower to expand and replenish this crucial resource in the socio-economic system.

Put more precisely, the model presents a flow system in which goals, resources, technological knowledge, and related information flow through varying networks of institutions, organizations, groups, and individuals. The goals, which include problems, opportunities, needs, limitations, objectives, etc., range from the most general socio-economic goals to highly specific technological or operational objectives. The flow of resources involves financial resources, professional and technical manpower, facilities and equipment, natural resources, materials, energy sources, etc., and includes the transformed resources which are

introduced into the socio-economic system in the form of technological innovations. The substantive scientific and technological knowledge includes the full range of scientific, engineering, and technical information: from fundamental findings in basic science through to detailed operational specifications. The related information included in the flow refers to the implications of substantive knowledge, the requirements for and availability of resources, the desirability and acceptability of goals, and information regarding prevailing or possible patterns of institutions and organizations involved in technological activities and related decision making processes.

These elements - goals, resources, knowledge, and related information - flow through varying networks of institutions, organizations, groups, and individuals engaged in technological activities and associated decision processes to produce the technological innovations that enter the socio-economic system. The technological activities can be grouped together in the four major modes of research, invention and development, other engineering, and operations. The associated decision processes are of two sorts: The first, which we have termed socio-economic, refer essentially to the selection

and determination of goals, the acquisition and allocation of resources, and the appraisal of technological innovations. The second, which we have called conversion processes, refer to the conversion of goals and resources, and their coupling together; and to the conversion of the implications of substantive scientific and technological knowledge into the form of proposed programs, projects, or policies.

In the course of technological innovation, innumerable variations can and do occur: in the configurations and characteristics of institutions, organizations, groups, and individuals involved; in the prevailing patterns of goals, resources, and technological knowledge; and in the specific sequences of technological activities and decision processes that occur.

Thus at one extreme, the institutional configuration could consist of a single, giant, scientifically-oriented corporation which spanned the entire system and encompassed most of the functions in the model. Such a corporation could have its own research laboratories, several development facilities and engineering organizations, and a number of operational

divisions. Its middle management groups could be engaged in the full range of conversion processes, and its top management and board of directors could perform the socio-economic functions of goal selection and determination, and resource acquisition and allocation. Its inhouse scientific and technical information services and its subscription to, and participation in, external information services and activities would cut across the communication systems of science and technology. Finally its inhouse and external technological training programs for its own personnel, and those designed to educate industrial customers in possible uses of new technological products and processes would establish the corporation as part of the educational system of science and technology. Thus a single corporation could encompass the entire model; and conversely the model could be used to analyze innovative processes in the context of a single corporation.

As an intermediate possibility, single institutions or organizations could encompass horizontal or vertical segments of the model, or combinations thereof. Thus a large, non-profit research organization could vertically include research activities, related

conversion processes, and certain of the socio-economic functions with respect to research. A small contract R&D corporation could horizontally span both the research and development activities, but might not extend vertically into the conversion segment to any significant degree. A small specialized engineering firm might be limited largely to the engineering activity mode; or a small sub-contract manufacturer to the operations mode. A government agency with inhouse laboratories and engineering facilities could span substantial portions of the model, both horizontally and vertically; whereas other government agencies and offices could be limited to performing certain socio-economic or conversion functions. Single individuals or groups of individuals could, of course, separately perform many of the functions including: research, invention, engineering, conversion of technological implications into proposed programs, providing financial resources, etc.

At the other extreme, the institutional configuration could consist of complex situations in which many of the particular functions were performed by intricate networks of organizations. Thus with respect to large-

scale technological innovations such as the Super Sonic Transport, the conversion processes could be carried out by a combination of government agencies, outside research and consulting organizations, and various advisory commissions, boards, and panels. Similarly the socio-economic function of goal determination with respect to innovation in urban housing patterns is usually exercised by a complex network of federal, state, and local government agencies, community groups, business interests, educational and charitable organizations, etc.

Other variables of major importance in the processes of innovation, which can be specified for each situation under study and analyzed within the framework of the model, include: the specific characteristics of individual organizations involved in configurations of the model (including their capabilities, policies, and practices); the particular patterns of goals, resources, technological knowledge, and proposed programs, projects, or policies that may be provided as input entities; and broad environmental conditions and constraints, such as tax laws, anti-trust policies,

the patent system, competitive patterns in a particular industry, the attitudes of the banking community in a particular region, etc.

Perhaps the most significant variation possible in the functioning of the model, however, is that of the specific sequence of technological activities and decision processes which characterizes each technological innovation. These innovational sequences vary widely in a number of ways. The first kind of variation arises from the fact that innovational sequences can start from a number of different points in the model. It is not necessary - and indeed is infrequent - that research activities lead directly to a technological innovation. Most research results enter the reservoir of scientific and engineering knowledge and are not incorporated in technological innovations until some time in the future, if at all. It is much more common for innovational sequences to start with invention or development activity, or with 'other engineering', and to draw upon substantive knowledge that has been in the reservoir for a number of years. Nor does an innovational sequence have to begin in one of the technological activity modes; it is quite possible for

technological innovations to commence in the conversion segment, with the recognition of the potential value to the socio-economic system of certain scientific or engineering possibilities. Similarly the impetus for an innovational sequence can come from segments of the wider socio-economic system, which impose goals requiring technological resolution, even without any anticipation of the kinds of technological approaches that may be employed. Specific innovational sequences can start from any of these sources, or as the convergence of several of them.

The second kind of variation arises from the fact that irrespective of where an innovational sequence commences, it usually does not have to traverse all of the remaining steps or functions in the model. For example, if an innovational sequence started with Step 31 (the transmission of the engineering implications of new technological capabilities to an engineering conversion organization), C_e would not have to carry out Step 33 (searching the communication system for alternative technological possibilities pertinent to its goals). Nor is it necessary that Step 43 be carried out, involving the feedback to C_e of implications regarding additional engineering that may be desirable.

The third kind of variation arises from the number of times a particular function is carried out within any innovational sequence. Thus function number 25 (searching existing sources of scientific and engineering knowledge for relevant information) may be performed a great many times in the course of a particular development project.

The fourth form of variation occurs in the way particular functions are carried out in practice. In discussing the model we have occasionally referred to these functions as if they were discrete and indivisible. This is, of course, not the case. Each function is itself the composite of many other sub-functions; and the performance of a particular function usually takes place over a period of time, entailing a number of interactions between the organizations or individuals involved. Consider, for example, function 16 (A_r transmits to C_d the development implications of new research knowledge). Assume that A_r has already established a relationship with an appropriate C_d. It still may be the case that the first transmission of these implications may not succeed in conveying their significance to C_d. At some later time, C_d may recall these implications in

connection with some other information which happens to highlight their significance. As a result C_d may request A_r to repeat the transmission. This time C_d may become quite interested, but perhaps the communication may omit estimates of the resources required to pursue the suggested developments, so that C_d has to request additional information to provide such estimates. Thus there may well be a series of interactions between A_r and C_d merely to complete what the model treats as a single function. In addition to such variations in the interaction pattern through which particular functions are performed, there are of course innumerable variations in the problem areas that may pertain in any case. Thus 16. a. (accepting the responsibility to carry out this function) may be extremely significant in one case, and trivial in another; similarly 16.c. (identifying an appropriate C_d to carry out the conversion processes) may be of overriding importance in one instance, and completely inconsequential in another.

The fifth form of variation in innovational sequences arises as a result of recyclings which are extremely common in the course of technological innovations. The recyclings are generally triggered by the various feedback functions in the model, or by selections from the reservoirs of knowledge. Thus

the feedback of implications from the development activity (function 28) could indicate to the conversion organization that additional development is required in order to accomplish the original goals, thereby setting in motion a further development effort along the lines indicated. On the other hand, the feedback could indicate other promising areas of development that could be pursued. In that case, the conversion organization could convert those implications into proposed new programs for submission to the socio-economic system, thereby leading to an entirely new innovational sequence. For example, the information provided to S_d by C_d could trigger a feedback from S_d to S_r, which in turn could lead to new research goals and a new sequence of research activities. Information selected from the communication reservoirs can also serve to generate recyclings or entirely new innovational sequences. Thus as a result of information selected from the communication system, a development organization may decide to re-do or modify certain portions of the development effort. Similarly while searching in the communication system for a particular kind of information, a research organization may stumble upon information of major

significance to certain of its other goals, which may precipitate an entirely new research project.

These recyclings are particularly common in composite innovations, consisting of a number of technological components which constitute innovations in their own right. In such cases, each component innovation generally has its own innovational sequence which it traverses through the model. The sequence of the overall, composite innovation is itself a composite of the sequences of each of the components, interlocked with one another through various recyclings. Perhaps recyclings are most important, however, with respect to diffusion of innovations among various firms within an industry, or from one industry to another. Diffusion recycling occurs when one organization selects from the communication reservoirs information regarding technology employed by another organization, thereby setting in motion new sequences that enable the selecting organization to adopt the innovation and adapt it to the organizations's own uses.

The preceding discussion elucidates an important, distinguishing feature of this systems model. This is the fact that the model is essentially a framework

of interrelated functions and sub-functions which collectively comprise the processes of technological innovation. Within this broad framework of interrelated functions (which in effect constitute the constants of the model), we can vary: the configurations and characteristics of the organizations engaged in carrying out those functions; the general environmental conditions and constraints which circumscribe the course of innovational events; the patterns of goals, resources, and technological knowledge which flow through the model; and the specific innovational sequences which are traversed in the course of particular technological innovations.

The various flows which occur within the framework of the model are designed to accord with the processes of technological innovation as they actually occur in practice. The typical process-flow model exemplifies the idea of one or several entities being propelled across a system, with one or more entry points at which the impetus or propulsive force is provided. The inclusion of feedback loops in such systems does not basically change this concept. This notion of propulsion across a system is included in this model too; but

it is combined with two other concepts which collectively impart a different character to the model, and render it reflective of the underlying realities of technological innovation.

The first is the concept of conversion of goals, resources, and knowledge, which is an essential ingredient of technological innovation. Only by means of the involved conversions we have described is it possible for the intricate complexities of technology to be shaped in a form that can serve the needs of the society, and match and meet the manifold opportunities that are presented. For only by means of such conversions can the diverse segments of the socio-economic system (including the modes of technological activity) communicate and interact effectively with one another, and direct their resources and talents toward common ends. Thus the introduction of the concept of conversion (with its related process of coupling) into the model imparts a certain sophistication to the flow situation, rendering it analogous to a complex electronic network, rather than the straightforward flow of a simple physical substance.

The second concept which characterizes the flow situation in this system is that of 'selection'. This critical function occurs at a number of key points throughout the model. There is selection of goals in the socio-economic system; selection of substantive scientific and technological knowledge in the activity spectrum; selection of other scientific and engineering possibilities pertinent to certain goals by conversion organizations; and selection, from a number of alternatives, of specific technological possibilities to be pursued. These selections are central and crucial to the course of innovations. Technological innovation does not occur in a linear, determinate pattern: proceeding inevitably from basic research through applied research through development and engineering until it triumphantly enters the socio-economic system. This simplistic concept has long been discarded by researchers versed in the realities of this field.

The success of technological innovation depends, in the final analysis, on the unpredictable actions of individuals: on their imagination, their judgment, and their willingness to commit their time, talents, and reputations to difficult courses of action in

situations of considerable uncertainty and risk. Any systems model purporting to encompass the processes of technological innovation must incorporate the concept of selection as an essential function at key decision points in the model. For it is by means of skillful selections from the communication system that scientists and engineers can enhance their own activities with the relevant results of their predecessors and contemporaries. It is by means of the similar selection of goals that decision makers in the socio-economic system can influence the course of technological innovation in socially desirable directions. And it is by means of selections of scientific and engineering possibilities pertinent to goals, and by choice among alternative possibilities, that decision makers in the conversion segment can match and fuse technological possibilities with the needs and opportunities of the society.

Fusion is fundamental to technological innovation: the fusion of goals and resources; the fusion of patterns of knowledge; the fusion of diverse interests and points of view; and finally the creative fusion of socio-economic needs and opportunities with new technological capabilities. Because the model incorporates

the converison and selection functions at key decision points in the system, it is capable of depicting this fusion as it actually occurs, and of systematically analyzing the functional interrelationships involved, without unrealistically disregarding the creativity and unpredictability inherent in innovative processes. Inclusion of the conversion and selection functions in the system also enables the model to be responsive to the needs, opportunities, and demands of the society; i.e., incorporation of these functions engenders a model that can assist in assessing the responsiveness of particular innovative patterns and practices to those needs, opportunities, and demands.

Consideration of the role of selection in the model highlights another system characteristic which also reflects the underlying realities of innovative processes. This is the fact that only a small portion of scientific and engineering knowledge can be incorporated in technological innovations which enter the socio-economic system. Some new knowledge will never find its way into useful application in the socio-economic system; other new knowledge will eventually prove useful, but not within any short time span.

These conclusions follow from consideration of the following factors: First, certain research results can not be useful to the socio-economic system unless and until they are combined with other items of knowledge which may not yet have been discovered or created. Accordingly, the research results have to remain in the information storage system of science and engineering until the other items appear, with which they can be combined. Second, certain knowledge can technically be used in the society, but there may be no need, demand, or opportunity for such use at that point in time. Thus it must remain in the information storage system unless and until there is such a need, demand, or opportunity - which some conversion organization recognizes. Third, certain knowledge may be technically useful to society, and there may be a need, demand, or opportunity for such use; but associated parameters, such as cost, may prohibit introduction of the innovation into the socio-economic system. In such cases, additional engineering, development, or even research may have to be undertaken in an attempt to alter the inhibiting parameters. Fourth, by the time any one of the first three sorts of innovations

is ready for introduction into the society, an alternative innovation may have emerged which meets the needs, demands, or opportunities far more effectively, thereby foreclosing the possibility of its ever being introduced. Fifth, even when alternative innovations do not emerge to supplant the ones which have been germinating, the socio-economic system itself is always changing; so that the particular needs, demands, or opportunities may lapse before the innovation is ripe for introudction.

For all of these reasons it is clear that not all new technological knowledge can be expected to find its way into useful technological innovations that enter the socio-economic system. This point may appear obvious, but some technology transfer programs have been designed without due regard for it. The particular agencies and organizations responsible for certain new technological areas surely have a right and responsibility to explore and develop ways in which their technologies can be effectively utilized in other fields. Certainly the society as a whole should attempt to exploit new technological possibilities for all they are worth. Technology is a resource subject to exploitation, just

as is oil, or coal, or copper. But just as mining has to be conducted within constraints designed to protect the environment, preserve the overall supply of resources, and assure responsiveness to applicable economic and social considerations, so too should technology transfer programs focus more on user needs and demands than some have heretofore. Furthermore, they should recognize that extremely rapid and widespread utilization of new technologies is not always a realistic objective, even if it were entirely desirable.

Returning to the model, we note that the processes of technological innovation require ample reservoirs of scientific and technological knowledge from which scientists and engineers can select substantive knowledge to be utilized in their activities, and from which decision makers can choose technological possibilities to be pursued. The bulk of scientific and technical knowledge will remain in these reservoirs; only limited portions can ever find their way into actual technological innovations.

Viewed from a more philosophical perspective, this phenomenon is only to be expected. Technological innovation is essentially a creative process; and

creative processes generally entail a large number of efforts that prove abortive for every outcome that is successful. This is surely true with respect to the biological propagation of species, and it appears to apply to the creative arts as well. Technological innovation is not exempt from such considerations.

B - Significance of the Model

The chief significance of this effort is that we have succeeded in constructing a single systems model of the processes of technological innovation: which spans the full spectrum of innovative processes from basic research through to use and appraisal in the socio-economic system; which is applicable to all kinds of innovations (specific products, composite products, processes, services, and systems); and which permits consideration of all kinds of institutions, organizations, groups, and individuals that may be involved in innovative processes. Critical consideration of this report will undoubtedly reveal flaws and shortcomings in the model as presently constructed; in addition certain areas and aspects of it clearly require further exploration and elaboration. Nevertheless, the model does do the basic job for which it is intended. It provides a coherent framework of interrelated functions, within which one can systematically describe and analyze the many variations in the processes of technological innovation as they occur in practice. The sixty-one interrelated major functions or steps of the model,

together with the more than two hundred sub-functions and problem areas involved in performing the major functions, comprise a framework for analysis which can be applied to all areas and aspects of technological innovation. Furthermore, the model has been deliberately designed so that it can be readily adjusted, expanded, and elaborated in response to critical comments from experts in this area, future research findings, and additional experience in applying it in practice. Despite whatever shortcomings it may subsequently display, we have succeeded in demonstrating for the first time that the processes of technological innovation can be realistically encompassed in a single systems model.

The import of this accomplishment is clear when one considers the pervasive impact and profound effects of systems analysis in recent years. Once an area can be encompassed in a realistic systems model, it becomes susceptible to sophisticated techniques of analysis which engender a level of understanding and influence unlikely to be achieved through other means. As has been repeatedly emphasized, the systematic analysis of innovative processes does not in any way deny or denigrate their creative, unpredictable aspects, or

overlook the wide variations possible in practice. Intelligent application of this systems model, however, can assist in predicting those aspects of innovation that are predictable, in directing those sequences of events that are subject to direction, and in structuring strategic elements of the socio-economic environment along lines designed to facilitate the flow of innovation.

The major implication of the model arises from the fact that its underlying concepts are extremely simple and, throughout its construction, every effort was made to keep the system as simple as possible - so long as it met the stated criteria. Despite earnest efforts toward this objective, however, the model as constructed turned out to be fairly complex: consisting of sixty-one major functions and over two hundred sub-functions or problem areas. The significance of this is clear. The processes of technological innovation are, in fact, exceedingly complex and penetrate almost all segments and facets of the socio-economic system. Moreover, they constitute far more of a complex, overlapping continuum of activities than they do a set of separate distinct functions (although

some such distinctions are essential if one is to undertake effective analyses of innovative processes).

In short, while simple in concept, the processes of technological innovation are exceedingly complex in practice. Efforts to influence their direction or enhance their effectiveness will prove of little avail, if they merely seek simplistic, short-term panaceas. Only a carefully conceived, concerted program that tackles these problems on a broad front over an adequate period of time can hope to accomplish results of real significance. Such a program must include measures for enhancing the overall environment in which innovative processes occur, for improving the climate of understanding and attitudes which affect decisions and actions in this area, and for facilitating fulfillment of the specific functions that must be performed to propel innovations into our socio-economic system. The systems model set forth in this report provides a powerful conceptual tool for developing and implementing such a program. Section C below considers the constituents required for a successful program of this sort.

C - Uses of the Model

Technological change has become crucial to the continued success of our economy and to the character of our civilization. With due regard for the creative, unpredictable elements in innovation, it is nevertheless essential for our society to achieve some measure of control over technological change, if we are to preserve and strengthen the values of our democracy and expand and enhance the opportunities for individual self-fulfillment. The systems model set forth in this report provides a powerful synthesizing mechanism which society can use to accomplish this objective.

Presented below is an overall, integrated program for applying the model to achieve this goal. The program consists of six interrelated areas of effort, which are designed to: (1) Strengthen the model further, while delineating the detailed techniques for applying it in practice; (2) Use the model as a mechanism for achieving a continuing integration of information in this area; (3) Conceive and conduct specific research projects in the framework of the model; (4) Undertake comparative analysis of the functioning of technological

innovation along a number of significant dimensions; (5) Assist administrators and policy makers by evaluating research results, proposals for new research and studies, and specific policy recommendations; (6) Use the model as a framework for an intensified educational effort to increase the level of understanding of innovative processes among researchers, administrators, policy makers, and practitioners. The application of the model in each of these areas is discussed in turn below.

(1) Further Development of Model. As extensive and involved as the model is, it still does not go into as much detail as might be desirable in certain areas, such as the technological activity modes, the communication systems, the educational system, etc. A great deal of relevant systems analysis and model building work has been done in recent years that could prove most useful in this respect, especially in the area of management of research, development, and engineering. This model can be used as the 'seed crystal' whereby detailed models of particular portions of innovative processes are collected and crystalized together into an integrated system. Other relevant models

can be analyzed, transformed into compatible components, and then incorporated into the overall model as sub-models for specific segments of the system. Eventually it might be desirable to have such sub-models for each of the major modes of technological activity, for the communication systems, the educational system, each portion of the conversion processes, and for goal determination and resource allocation in the socio-economic system. In any event this model can definitely be employed to bring together and integrate the best elements of other existing models of specific aspects of innovative processes. In particular areas for which there aren't any adequate existing models, new sub-models can be developed to the extent desirable.

Concurrent with the further elaboration of the model, it will be necessary to develop an arsenal of supporting analytical tools and techniques for applying the model to particular classes of problems. For example, if one wishes to plug a particular institutional-organizational configuration into the model, what are the key kinds of relationships among organizations and chief characteristics of individual organizations which ought to be included for various types of analyses? How should one

delineate the patterns of goals arising in the socio-economic system? What measures should be used to characterize the resources that are provided? What are the criteria of effectiveness to be employed in appraising alternative innovative policies and practices?

Similarly if one wishes to employ the model to aid in the area of technological forecasting, how can it be integrated with the variety of specific forecasting techniques that have already been developed? (These techniques focus mostly on predicting specific outputs of Steps 26 and 27 of the model: i.e., on delineating new technological capabilities, requirements, and problems likely to result from invention and development activities. Some attention has also been accorded to the problem of predicting the output of Steps 11 and 12 [new research knowledge]; but this is a much more difficult task. The model at its present level of elaboration cannot be of much assistance in making these specific predictions. It can, however, prove of considerable assistance in anticipating and assessing the course of events entailed in transforming the inventions and developments into innovations that enter the socio-economic system.)

These and a host of similar considerations and questions must be confronted and answered before the model can achieve its full potential. Only through repeated, extensive application of the model to particular problems in this area can the necessary methodology and specific techniques of analysis be developed in sufficient detail. The sort of problems to which it should be applied in order to develop these tools are described below in the discussion of the other portions of the program.

For the model to prove most useful over the long-run, it should serve as the foundation for a computer simulation system of the processes of technological innovation. Computer simulation would impart much more power to analyses based on the model - rendering them far more reflective of the underlying realities of technological innovation - by permitting the simultaneous consideration and comparison of alternatives involving enormous numbers of variables and interrelationships. The functions and relationships delineated in the model are definitely amenable to computer simulation, having been designed with this possible application in mind. Of course, designing a computer simulation system based on the model would

be a lengthy project in and of itself. Once it were completed, however, and realistic computer simulation of the processes of technological innovation were a practical possibility, society would be afforded enormous power to anticipate, assess, and affect the character of technological changes, and - to a limited extent - control their consequences.

(2) Continuing Integration of Information on Technological Innovation. Perhaps more so than in any previous time, information today is the prime source of power and control. Thus it is significant that the model can serve as a mechanism for achieving a continuing integration of information on technological innovation. The model provides a framework for the systematic collection, coordination, and analysis of information of three sorts: case studies, statistical data, and research results. Each of these is discussed in turn below.

There are many case studies in the field of technological innovation which provide a wealth of detailed data and a host of valuable insights. But the very specificity which renders these studies so valuable in the education of practitioners also precludes

their providing a sufficient basis for the generalizations required to guide effective policy making in this area. The model provides a means of transforming this data into a compatible form, subject to systematic analysis likely to yield additional insights and meaningful policy guidelines.

The case data would be transformed by restating each case in terms of the specific concepts and functions of the model. Thus the events contained in each case would be re-described by means of the functions and problem areas of the model. The resulting statement would elucidate the 'innovational sequence' actually followed in that case. For example, a particular case might start with Step 16 (transmission to a conversion organization of the development implications of new research knowledge). The re-description would identify the organizations involved in carrying out this function, and discuss the specific problems encountered in practice and the ways in which they were handled. It would then move on to the next function and similarly discuss the events which occurred in terms of the model. The completed re-description of the case would indicate the actual 'innovational sequence' with its repeated

functions, skipped functions, various recyclings, etc., and with consideration of the sub-functions and problem areas that were encountered in practice. The structure or order of events in each case situation could be precisely diagrammed by tracing the actual 'innovational sequence' of functions in the format of the model, including appropriate parameters such as time and cost. Of course there would be many gaps in these re-descriptions, since few existing case studies cover all phases of the innovation adequately. This problem could be mitigated somewhat by gathering additional data for certain cases and by making reasonable assumptions in other ones. New cases could also be collected that make explicit use of the concepts and functions of the model. In the long run such cases could prove extremely valuable. In any event, the collection of cases transformed in this way would provide a wealth of compatible data subject to systematic, comparative analysis: which in all probability would yield valuable insights into the processes of technological innovation.

Effective formation of national policies regarding technological innovation entails not only the sorts of insights that may be afforded through microscopic

analyses of case studies, but also requires the macroscopic comprehension that can be acquired only on the basis of extensive, sound statistical data. The best accumulation of statistics relevant to technological innovation is that collected periodically by the National Science Foundation with respect to research and development and scientific manpower data. The data instruments employed in these collections, however, were not deliberately designed to focus on technological innovation per se; accordingly they do not cover all important aspects of innovative processes. Some of these data gaps are met by other statistical sources, such as the Census Bureau and Bureau of Labor Statistics. Nevertheless, it can be said that there is not at present any comprehensive national collection of statistical data specifically directed at the processes of technological innovation. Such a collection, on a continuing basis, is essential for sound policy formation in this area. The systems model provides an excellent framework for designing a national data collection system of this sort (which could of course consist in part of modifications to existing national data collection efforts). The model could prove of assistance in the designation and definition of the

information categories to be used, in the delineation of their interrelationships, and in the actual design of questionnaires and other data collection instruments. In addition, the model could prove extremely useful in the analysis and appraisal of the information that is collected. After a computer simulation system is developed, much of the data could be analyzed by means of the computer; and could in turn provide the computer with an expanding bank of reliable data that would render its subsequent simulations more realistic.

In a dynamically developing area such as the study of technological innovation, it is essential to sustain a continuing assessment and synthesis of research results from the various projects in the field, indicating the significance of new findings and identifying important areas of ignorance requiring further exploration. Such a synthesis would integrate the various factual findings within the framework of the model, identify new or altered problem areas, and consider hypotheses, conclusions, and specific suggestions made in the light of the model. It might even be desirable to establish some sort of information service specifically directed at research in this area. In any

event, the model should be used to integrate research findings for the benefit of researchers, administrators engaged in related conversion processes, and policy makers in this field.

(3) Framework for Specific Research Projects. The model can, and certainly should, be used as the framework for conceiving and conducting specific research projects in depth in particular areas of the system. In this connection, the model can prove of most assistance in suggesting specific projects to be undertaken, in assessing their anticipated significance to the total system, and in designing the research in such a way as to assure attention to all relevant factors, including those in other segments of the system. For example, the model points up the fact that we possess very little detailed knowledge about how conversion processes are presently carried out, much less about how they might be carried out with other institutional and organizational arrangements. Successful research in this area could prove much more significant in enhancing technological innovation in our society than would studies aimed at improving the efficiency of particular development projects. This is not to imply

that the latter sort of study is unimportant; it is merely to place it in the proper perspective relative to the overall processes of technological innovation.

(4) Comparative Analyses. A fourth major application of the systems model is the conduct of comparative analyses of the varying functioning of technological innovation along a number of significant dimensions, such as: organizational relationships and characteristics; environmental conditions and constraints; types of innovations; sectors of the economy; specific kinds of industries; and different regions of the country. For each situation to be studied, 'innovational profiles' can be developed, consisting of typical configurations of institutions, organizations, policies, goals, resources, and patterns of technological knowledge and communication characteristic of innovation in that situation. Several 'innovational profiles' would probably be required in each area in order to reflect realistically the major variations in innovative activity. The main problem in delineating such profiles, of course, would be posed by the lack of sufficient reliable data regarding specific points in the profile. The store of such data would increase in time, particularly if the data collection program outlined above is undertaken. In

the interim, reasonable assumptions could be made in order to complete the profiles. As with the re-described case studies, the 'innovational profiles' would provide compatible data on the functioning of innovation along a variety of important dimensions. The profiles could be subjected to comparative analysis regarding the points of similarity and differences in the fulfillment of each function in the varying situations.

Thus along the dimension of organizational relationships and characteristics, separate profiles could be developed for innovative processes in the context of large corporations, medium-size corporations, small firms, scientifically and non-scientifically oriented organizations, individual inventors and entrepreneurs, corporations with a centralized structure and ones with decentralization, etc. With respect to environmental conditions and constraints, different profiles could be developed reflecting variations in innovative processes under alternative tax laws, anti-trust policies, patent regulations, competitive situations, differing levels of venture capital availability, etc. Other profiles could be developed to illustrate the differences in innovative processes depending on whether the innovation

is a specific product, a composite product, a process, a service, or a complex system. A particularly important subject for comparative analysis consists of different sectors of the economy. Thus separate profiles could be delineated to reflect innovation in the defense sector, in the non-defense public sector, in the private sector, in the non-profit, academic R&D complex, etc. Similarly profiles could be delineated for different types of industries (consumer product industries, industrial supply industries, appliance manufacturers, mass production industries, fragmented craft industries, etc.); and for different specific industries (textiles, chemicals, machine tools, electronics, furniture, etc.). Finally, 'innovational profiles' could be delineated for different geographic regions (Boston, Philadelphia, California, Appalachia, etc) taking account of relevant regional factors, such as: market composition, resource supplies, manpower skills and availability, attitude of the financial community, etc. In addition to 'innovational profiles' along each of these dimensions, profiles could be delineated which take account of several dimensions simultaneously. Thus one could contrast the functioning of innovation in the defense

and non-defense sectors of specific industries such as chemicals, electronics, food processing, textiles, etc. Similarly, one could delineate profiles reflecting innovation in the area of defense aerospace systems; and compare them with profiles of innovation in complex socio-economic systems in areas such as urban affairs, transportation, education, pollution controls, etc. Construction of a number of such 'innovational profiles' within the framework of the model would provide a powerful tool of comparative analysis that would inevitably enhance our understanding of innovative processes.

(5) Aid to Administrators and Policy Makers. The fifth major application of the systems model is to assist administrators and policy makers in the evaluation of research results, proposals for new research and studies, and specific policy alternatives and recommendations. The model could aid in evaluating the significance of new research results in relation to the total body of existing knowledge, and in terms of their implications for the overall processes of technological innovation. Similarly, proposals for new research and studies could be evaluated not only

on their substantive merits, but also in relation to the total body of knowledge and to significant areas of ignorance requiring further exploration. Finally, the model can be used in suggesting and evaluating specific policy alternatives and recommendations. By means of the model, they can be appraised not only in terms of the particular problems they purport to solve, but also in terms of the associated problems they will inevitably pose. Within the framework of the model, the policy maker will be enabled to focus his decision on their strategic significance to the overall processes of technological innovation. Consider, for example, the problem of conserving and utilizing innovative resources currently in use in the defense sector of the economy, in the event of substantial curtailments in defense spending for research, development, and engineering. By means of the 'innovational profiles' discussed in (4) above, detailed comparative analysis could be conducted of the patterns and problems involved in carrying out each of the functions of technological innovation in both the defense and non-defense sectors. Thus the policy maker would be enabled to anticipate and plan for the specific problems that would be encountered

in attempting to convert defense industry innovative resources for use in the non-defense sectors.

(6) Aid in Education. Finally, as its sixth major application, the model constitutes a comprehensive framework for an intensified educational effort in this area. The systems model can be utilized to assist in the design and stimulation of a variety of seminars, symposia, and training programs, each specially tailored and directed toward key audiences in this area: researchers in the field; practitioners in a variety of industries and different kinds of organizations; decision makers at different levels in different sorts of institutional contexts; and high level policy makers whose decisions affect the overall environment in which innovation must occur.

This educational function may well prove to be the most important application of the model. For in the final analysis the extent and effectiveness of technological innovation depend on specific individuals - on the qualities of understanding and imagination, astuteness of judgment, and intensity of personal commitment which they manifest in situations of uncertainty, often at great personal risk to their careers, financial positions, and reputations. For these individuals to achieve their maximum effectiveness, they must have enhanced comprehension of the processes

of technological innovation. Certainly it is not necessary or possible for individuals to have detailed understanding of all or even most aspects of innovative processes. But it is important that they do understand those aspects of innovative processes which impinge on their own sphere of activities, or which are affected by their actions. The systems model of the processes of technological innovation can make a major contribution toward imparting such understanding.

The central proposal of the Panel on Invention and Innovation (Technological Innovation: Its Environment and Management, pp. 56 and 57) is as follows:

> "The major effort should be placed on getting more managers, executives, and other key individuals--both in and out of government--to learn, feel, understand and appreciate how technological innovation is spawned, nurtured, financed, and managed into new technological businesses that grow, provide jobs, and satisfy people . . .
>
> "Summing up, we find that the concepts, uncertainties, and other realities of technological innovation are like a foreign language, indeed a strange world, to too many of us. Because of this, we believe the most important initial task before us is to become more widely acquainted with the 'language' and 'world' of innovation.

"Understanding, as Alexander Pope might have put it, is the key to a drawer wherein lie other keys. When we come to appreciate and understand the problems and the opportunities associated with innovation, we can more effectively act on programs that will best encourage beneficial change and the continued renewal of our society."

CHAPTER SIX

SUMMARY AND CONCLUSION

A - Purpose

The character and consequences of technological change have become crucial to the course of our civilization. It is essential to take measures to assist in anticipating, assessing, and affecting the character of these changes, and in controlling their consequences. For such measures to prove most effective, they should be conceived and implemented within a coherent conceptual framework that realistically encompasses the processes of technological innovation as they occur in the context of our socio-economic system. This report submits such a conceptual systems model for the critical consideration of researchers, practitioners, and policy makers in this area.

The model focuses on the various ways in which the structure of socio-economic institutions and organizations, in combination with particular patterns of goals and resources, promotes or impedes the processes of technological change; and the ways in which scientific knowledge is transformed into inventions, and inventions are incorporated in innovations that enter the wider socio-economic system where they are used and appraised

and the results fedback to affect the further formulation of goals and policies and the related allocation of resources.

The systems model has been designed to facilitate the analysis and appraisal of research proposals and alternative public policies aimed at elucidating or enhancing the processes of technological innovation throughout our nation, with special emphasis on proposals and policies directed at innovation in the civilian sector of the economy. The kinds of objectives that could be furthered by application of this model include:

(1) increasing the overall rate of technological innovation in our society;

(2) stimulating the introduction of innovation in technologically underdeveloped areas (including sectors and segments of the economy, as well as geographic regions of the nation);

(3) improving the effectiveness with which technological innovations are conceived and carried out;

(4) increasing the diffusion of technological innovations within industries and across industries and sectors of the economy;

(5) enhancing the responsiveness of technological innovation to the needs, opportunities, and demands of the society; and

(6) planning for the conservation of defense industry innovative resources in the event of substantial curtailments in defense spending, and for the effective transfer and utilization of such resources in other sectors of the economy.

B - Underlying Assumptions and Concepts

The model is based on the assumption that although innovative events are creative and unpredictable, they constitute a set of interrelated processes subject to systematic scrutiny and study. The underlying concept of the model is that the processes of technological innovation can be described as complex combinations of interactions among three distinct factors: goals, resources, and technological knowledge. These three factors interact in a variety of ways in the context of varying institutional and organizational configurations so that any innovation can be described as a complex sequence of such interactions.

Chart 2, The Interaction of Goals, Resources, and Technological Knowledge (pg. 22) illustrates four basic forms of interaction among these elements: transformation of resources; allocation of resources; conversion of goals; and creation of new knowledge. The transformation of resources occurs through the application of technological knowledge to the resources, in the context of the operational activity, in order to accomplish the goals. As a result, some portion

of the resources is transformed into products, processes, services, or systems for use in wider segments of the socio-economic system. Technological innovation occurs when the technological knowledge involved in the interaction results in the emergence of novel characteristics in the: (a) input, (b) output, or (c) framework or conduct of the operational activity. The technological knowledge leading to a technological innovation does not itself have to be new. It is the novel way in which technological knowledge is applied that is essential to technological innovation.

The diagrams in Chart 2 (pg. 22) are highly oversimplified. To account realistically for the normal flow of activities and communication among the organizations and individuals involved in the processes of technological innovation, we rather rapidly move from the simple illustrations of Chart 2 to an increasingly complex set of interactions. The systems model attempts to take account of the full range of factors and interactions involved in the processes of technological innovation: (a) providing for all sorts of innovations, including products, processes, services, and systems; (b) spanning the

spectrum from basic research through use and appraisal in the socio-economic system; and (c) permitting consideration of alternative environmental conditions and varying configurations of institutions and organizations that may be involved in specific innovational situations.

C - Construction of the Systems Model

Chart 3, Technological Activities in the Socio-Economic System (pg. 34), depicts the socio-economic system as including four major modes of technological activity: research; invention and development; other engineering; and operations. Major modes of technological activity refer to those activities directed at the creation of new technological knowledge and the application of that knowledge to transform resources into new products, processes, services, or systems for use in wider segments of the socio-economic system. The major modes of technological activity constitute far more of a complex, overlapping continuum than they do a set of separate distinct activities; yet some such distinctions are essential to undertake effective analysis of innovative processes. The model defines the four major modes of technological activity as follows: (1) research shows what is possible; (2) invention and development activity makes what is possible actually happen in a particular case; (3) 'other engineering' takes that particular case and adapts it for useful incorporation in the socio-economic system; and (4) operations actually introduces the innovation into the socio-economic system.

Chart 4, The Substratum of Communication (pg. 47), introduces the scientific and engineering communication system and the technological-industrial communication system into the model; and Chart 5, The Flow of Substantive Scientific and Technical Information (pg. 52), illustrates the ways in which the major modes of technological activity interact with one another through the medium of the communication systems. The institutions and organizations engaged in research, invention, and development select information relevant to their goals from the science and engineering communication system; and use the information to help create new knowledge which is entered into the same communication system. Organizations engaged in 'other engineering' activity similarly select relevant information from the technological-industrial communication system; and create technological knowledge in the form of precise operational specifications which are transmitted directly to the appropriate operational activity.

Chart 6, The Science and Engineering Educational System (pg. 62), introduces this important constituent of the system. The educational system receives goals and resources from the socio-economic system, selects scientific and technical information from the communication

systems for use in educational processes, and provides the socio-economic system with new science and engineering manpower, enhanced public understanding of science and technology, and requests for further resources.

Chart 7, The Internal Technological Gap (pg. 64), indicates the wide gap that has to be crossed in order for the socio-economic system to interact with the modes of technological activity and enable innovations to emerge. On the chart the arrows moving down from the socio-economic system represent either goals or resources. The term goals refers to any set of factors intended to influence the direction or nature of activity in the technological activity spectrum (e.g., problems,opportunities, objectives, limitations, etc.). Resources include: manpower (both professional and technical), as well as facilities, equipment, materials, energy sources, funds, and any other resources that can be provided by the socio-economic system for utilization in technological activities (such as the allocation of certain bands of the radio frequency spectrum for research in radio astronomy). The arrows moving upward from the activity spectrum toward the socio-economic system all represent forms of information: the implications of past research; the implications of

new research; information about new technological capabilities, requirements, and problems; and information on specific capabilities and associated costs. This information does not contain substantive scientific or technical knowledge; rather it is information about the substantive knowledge, expressing the implications or expected significance of the substantive knowledge to the socio-economic system. The effective determination of goals and allocation of resources for technological activities depend on the early and astute assessment of the implications of substantive technological knowledge; and the effective derivation and delineation of these implications depend in turn on sound foreknowledge regarding emerging patterns of socio-economic goals and resources. As indicated on Chart 7, however, the 'internal technological gap' or communication chasm separating these segments of society precludes the direct interaction of these elements.

Chart 8, Conversion Processes (pg. 71), introduces a significant new set of functions into the model, which serve to bridge the gap and permit the processes of technological innovation to occur. The net effect of a whole sequence of conversion processes is shown

at the right of the chart, as the input to the operational activity of specific operational objectives and resources. These are combined, within the context of the operational activity, with technological knowledge in the form of precise operational specifications provided by the engineering activity. The result is the transformation of certain of the resources into the technological innovation - as shown previously in Chart 2a, pg. 22 - which enters the socio-economic system where it is used and appraised, and the appraisals fedback to affect the future formulation of goals and allocation of resources. Thus the conversion processes complete the dynamics of the systems model, and enable the full flow of activities involved in the processes of technological innovation to occur.

The major functions involved in conversion processes are as follows: First is the conversion of certain general goals of the socio-economic system into specific goals, presented in a form that is comprehensible to individuals in the activity spectrum and capable of influencing the direction of their efforts. Second is the conversion of resources provided by the socio-economic system into a form that is useful to the organizations in the activity spectrum. Third is the

coupling of goals and resources together and providing them to the activity spectrum in a combined package so that specific resources can be directed toward specific goals. Fourth is the conversion of information on the implications of substantive technological knowledge into proposed programs, projects, or policies for submission to other decision making agents in the socio-economic system.

D - The Processes of Technological Innovation

Based on the underlying assumptions and concepts set forth in Section B and constructed in the manner described in Section C, Chart 10 (The Processes of Technological Innovation, pg. 124) depicts the overall systems model. The sixty-one major functions in the model are as follows:

1. A_r transmits the implications of past research to C_r.
2. S_r transmits goals for research to C_r.
3. C_r searches existing sources of knowledge to select out other science and engineering possibilities relevant to the goals.
4. C_r selects specific scientific and engineering possibilities that should be pursued.
5. In light of the goals with which it has been provided, C_r converts the selected scientific and engineering possibilities and estimated resources required into proposed programs, projects, or policies for submission to S_r.
6. C_r transmits the proposed programs, projects, or policies to S_r.
7. S_r provides research resources to C_r.
8. C_r converts the goals received from S_r into a form communicable to A_r, and couples the goals with the resources that have been provided.
9. C_r transmits the goals and research resources to A_r.

10. A_r searches existing sources of scientific and engineering knowledge to select out that information relevant to the goals and within the limitation of available resources.

11. In light of such goals as may be given, within the limitations of available resources, and making use of selected scientific and engineering knowlege, A_r carries out research which creates new knowledge.

12. A_r recognizes the implications of new scientific and engineering knowledge.

13. A_r feeds back to C_r the implications of new knowledge with respect to further research.

14. A_r transmits the new knowledge into the science and engineering communication system.

15. The new knowledge is incorporated into the total body of scientific and engineering knowledge.

16. A_r transmits to C_d the development implications of new research knowledge.

17. S_d transmits goals for development to C_d.

18. C_d searches the S&E communication system in order to select various scientific and engineering possibilities pertinent to its goals.

19. C_d selects from relevant science and engineering possibilities specific possibilities to be pursued.

20. In light of its goals, C_d converts the selected scientific and engineering possibilities and estimates of required resources into proposed programs, projects, or policies for submission to S_d.

21. C_d transmits the proposed programs, projects, or policies to S_d.

22. In response to the proposals that have been submitted (considered in the light of the goals and applicable socio-economic factors) S_d makes certain development resources available to C_d.

23. C_d converts the goals received from S_d into an effective form for presentation to A_d, and couples the goals with the resources that have been provided.

24. C_d transmits specific development objectives, coupled with related resources, to A_d.

25. A_d searches existing sources of scientific and engineering knowledge to select out that information relevant to the goals and within the limitations of available resources.

26. Within the limitations of resources provided, and making use of selected scientific and engineering knowledge, A_d carries out the invention or development activities directed toward its objectives: resulting in inventions, developed technology, and new problems and opportunities.

27. A_d delineates the new technological capabilities, requirements, and problems resulting from the invention and development activities.

28. A_d feeds back to C_d the implications of this information with respect to further development.

29. A_d inputs the new knowledge into the technological-industrial communication system.

30. The new knowledge is incorporated into the body of technological knowledge.

31. A_d transmits to C_e the engineering implications of new technological capabilities, requirements and problems.

32. S_e transmits goals for engineering to C_e.

33. C_e searches accessible segments of the technological-industrial communication system to select alternative technological possibilities pertinent to its goals.

34. C_e selects specific inventions and developments for further engineering activity.

35. C_e converts the information regarding specific technological inventions and developments into proposed engineering programs or projects, designed to meet the goals.

36. C_e transmits proposed engineering programs or projects to S_e.

37. S_e makes engineering resources available to C_e.

38. C_e converts the goals received from S_e into an effective form for presentation to A_e, and couples them with the resources that have been provided.

39. C_e transmits specific engineering objectives, limitations and resources to A_e.

40. A_e searches accessible sources of technological knowledge to select out that information pertinent to its engineering objectives within the context of the established limitations.

41. Within the limitations imposed, and making use of selected technological knowledge, A_e engages in engineering activity to meet the specific objectives and to generate the requisite operational specifications.

42. A_e elicits and compiles information on the capabilities, costs, and problems associated with the desired innovation.

43. A_e feeds back to C_e the implications of this information with respect to additional engineering.

44. A_e transmits the operational specifications to A_o.

45. A_e may provide some engineering feedback into the technological-industrial communication system.

46. A_e transmits information on the specific capabilities and costs of the innovation to C_o.

47. S_o transmits operational goals to C_o.

48. C_o utilizes the information on specific capabilities and costs to prepare proposed operational plans to meet the operational goals.

49. C_o transmits the proposed operational plans to S_o.

50. S_o makes operational resources available to C_o.

51. C_o converts the goals received form S_o into an effective form for presentation to A_o, and couples them precisely with the resources that have been provided.

52. C_o transmits specific operational objectives and resources to A_o.

53. A_o produces the technological innovation.

54. A_o introduces the innovation into the socio-economic system.

55. Segments of the socio-economic system (S_u) make use of the technological innovation; and various institutions, organizations, groups, and individuals (S_p) appraise its effectiveness and value.

56. S_p feedsback the results of its appraisals to those segments of the socio-economic system engaged in the determination of relevant goals and the allocation of related resources (S_r, S_d, S_e, S_o).

57. The socio-economic system provides goals and resources to the science and engineering educational system.

58. E selects scientific and engineering information that is up-to-date, significant and suitable to its educational objectives.

59. E selects technological-industrial information that is up-to-date, significant and suitable to its educational objectives.

60. In light of the goals and within the limitations of its resources, E makes use of selected scientific - technological - industrial knowledge to generate

trained scientific and engineering manpower and enhanced public understanding of science and technology (while delineating requirements for additional resources).

61. E provides the socio-economic system with S&E manpower, enhanced public understanding of science and technology, and requirements for additional resources.

E - System Characteristics

This section summarizes the general characteristics of the systems model. Referring to Chart 10 (pg. 124), the goals provided by the socio-economic system are much more general and exert much less control over the direction of technological activities at the far left, and become increasingly specific and exert more control as we move across the model. Similarly the resources provided by the socio-economic system generally become greater and greater in magnitude as we move across the model from left to right. The scope and significance of the information moving upward from the activity spectrum also change as we traverse the model. The implications of substantive scientific knowledge shown at the left-hand side of the chart usually encompass a wide band of possibilities. This band narrows progressively as we move across the chart. At the same time the short-run significance or immediacy of the implications is usually slight at the far left, and increases substantially as we move across the chart. Similarly the coupling of goals and resources at the research end of the system is generally far less extensive and far more flexible than the precise, detailed coupling of operational goals and resources

at the far right. The nature of technological activities also varies as the model is traversed. For example, the underlying conflict between creativity and control changes its character as we move from left to right. In basic research, creativity is clearly of maximum importance; whereas administrative control is paramount in the operational activity. The character of the communication system also changes: with communication usually much more fluid and free-flowing in basic research, and becoming progressively more rigid and restricted as we move into the technological-industrial area.

We may conceive of the model as a vast pumping system. The goals of the socio-economic system interact (in the context of the conversion segment) with the implications of substantive knowledge, resulting in proposed programs, projects, or policies which trigger the release of resources from the socio-economic system. These resources and goals are converted and coupled together in the conversion segment and pumped into the activity spectrum, thereby providing the fuel or propulsive force for the creation of new substantive knowledge. This knowledge is pumped across the activity spectrum through the medium of the communication systems,

which can be conceived of as consisting of interconnected reservoirs of knowledge. The result of these transformations is technological knowledge in the form of precise operational specifications which interact, in the context of the operational activity, with the operational objectives and resources to produce the technological innovation. The innovation is introduced into the socio-economic system, where it is used and appraised; and the results fedback to affect the subsequent selection and determination of goals, and the acquisition and allocation of related resources. Concurrent with these processes, the educational system continually siphons off selected substantive knowledge for use in generating new scientific and engineering manpower to expand and replenish this resource in the socio-economic system.

Put more precisely, the model presents a flow system in which goals, resources, technological knowledge, and related information flow through varying networks of institutions, organizations, groups, and individuals that are engaged in technological activities and associated decision processes, thereby producing the technological innovations that enter the socio-economic system. Thus the model is essentially a framework of interrelated functions and sub-functions which collectively comprise

the processes of technological innovation. Within this framework of interrelated functions (which in effect constitute the constants of the model), we can vary: the configurations and characteristics of the organizations engaged in carrying out those functions; the general environmental conditions and constraints which circumscribe the course of innovational events; the patterns of goals, resources, and technological knowledge which flow through the model; and the specific innovational sequences which are actually traversed in the course of particular innovations.

The typical process-flow model exemplifies the idea of one or several entities being propelled across a system, with one or more entry points at which the impetus or propulsive force is provided. The inclusion of feedback loops in such systems does not basically change this concept. This notion of propulsion across a system is included in this model too; but it is combined with two other concepts which collectively impart a different character to the model, and render it reflective of the underlying realities of technological innovation. The first is the concept of conversion of goals, resources, and knowledge: by means of which it is possible for the intricate complexities

of technology to be shaped in a form that can serve the needs of the society, and match and meet the manifold opportunities that are presented. The second concept is that of 'selection', involving: selection of goals in the socio-economic system; selection of substantive scientific and technological knowledge in the activity spectrum; selection of other scientific and engineering possibilities pertinent to certain goals by conversion organizations; and selection, from a number of alternatives, of specific technological possibilities to be pursued. These selections are central and crucial to the course of innovations. Technological innovation does not occur in a linear, determinate pattern: proceeding inevitably from basic research through applied research through development and engineering until it triumphantly enters the socio-economic system. Any systems model purporting to encompass the processes of technological innovation must incorporate the concept of selection as an essential function at key decision points in the model.

Fundamental to technological innovation is the fusion of goals and resources; the fusion of patterns of knowledge; the fusion of diverse interests and points of view; and finally the creative fusion of

socio-economic needs and opportunities with new technological capabilities. Because the model incorporates the conversion and selection functions at key decision points in the system, it is capable of depicting this fusion as it actually occurs, and of systematically analyzing the functional interrelationships involved, without unrealistically disregarding the creativity and unpredictability inherent in innovative processes.

F - Significance of the Model

The chief significance of this effort is that we have succeeded in constructing a single systems model of the processes of technological innovation: which spans the full spectrum of innovative processes from basic research through to use and appraisal in the socio-economic system; which is applicable to all kinds of innovations; and which permits consideration of all kinds of institutions, organizations, groups, and individuals that may be involved in innovative processes. The sixty-one interrelated major functions or steps of the model, together with the more than two hundred sub-functions and problem areas, comprise an analytical framework which can be applied to all areas and aspects of technological innovation. Intelligent application of this systems model can assist in predicting those aspects of innovation that are predictable, in directing those sequences of events that are subject to direction, and in structuring strategic elements of the socio-economic environment along lines designed to facilitate the flow of innovation.

The model demonstrates that the processes of technological innovation, while simple in concept, are exceedingly complex in practice. Efforts to influence

their direction or enhance their effectiveness will prove of little avail, if they merely seek simplistic, short-term panaceas. Only a carefully conceived, concerted program that tackles these problems on a broad front over an adequate period of time can hope to accomplish results of real significance. The systems model set forth in this report provides a powerful conceptual tool for developing and implementing such a program.

G - Uses of the Model

The proposed program consists of six interrelated areas of effort, which are designed to: (1) Strengthen the model further, while delineating the detailed techniques for applying it in practice; (2) Use the model as a mechanism for achieving a continuing integration of information in this area; (3) Conceive and conduct specific research projects in the framework of the model; (4) Undertake comparative analysis of the functioning of technological innovation along a number of significant dimensions; (5) Assist administrators and policy makers by evaluating research results, proposals for new research and studies, and specific policy recommendations; (6) Use the model as a framework for an intensified educational effort to increase the level of understanding of innovative processes among researchers, administrators, policy makers, and practitioners. The application of the model in each of these areas is discussed in turn below.

(1) Further Development of Model. As extensive and involved as the model is, it still does not go into as much detail as might be desirable in certain areas. Other relevant models can be analyzed, transformed

into compatible components, and then incorporated as sub-models for specific segments of the system. In particular areas for which there aren't any adequate existing models, new sub-models can be developed to the extent desirable. Concurrent with the further elaboration of the model, it will be necessary to develop an arsenal of supporting analytical tools and techniques for applying the model to particular classes of problems. Only through repeated, extensive application of the model to particular problems in this area can the necessary methodology and specific techniques of analysis be developed in sufficient detail. For the model to prove most useful over the long run, it should serve as the foundation for a computer simulation system of the processes of technological innovation. Computer simulation would impart much more power to analyses based on the model - rendering them far more reflective of the underlying realities of technological innovation - by permitting the simultaneous consideration and comparison of alternatives involving enormous numbers of variables and interrelationships.

(2) Continuing Integration of Information on Technological Innovation. The model provides a framework for the systematic collection, coordination, and analysis of information in three categories: case studies, statistical data, and research results. The very specificity which renders case studies so valuable in the education of practitioners also precludes their providing a sufficient basis for the generalizations required to guide effective policy making in this area. The model provides a means of transforming this data into a compatible form, subject to systematic analysis. The case data would be transformed by restating the events in each case in terms of the functions and problem areas of the model; so that the resulting statement would elucidate the 'innovational sequence' which was actually followed. The structure or order of events in each case situation could be precisely diagrammed by tracing the actual 'innovational sequence' of functions in the format of the model, including appropriate parameters such as time and cost.

Effective formation of national policies regarding technological innovation entails not only the sorts of insights that may be afforded through microscopic analyses of case studies, but also requires the

macroscopic comprehension that can be acquired only on the basis of extensive, sound statistical data. There is not at present any comprehensive national collection of statistical data specifically directed at the processes of technological innovation. The systems model provides an excellent framework for designing a national data collection system of this sort (which could of course consist in part of modifications to existing national data collection efforts). The model could prove of assistance in the designation and definition of the information categories to be used, in the delineation of their interrelationships, and in the actual design of questionnaires and other data collection instruments. In addition, the model could prove extremely useful in the analysis and appraisal of the information that is collected. After a computer simulation system is developed, much of the data could be analyzed by means of the computer; and could in turn provide the computer with an expanding bank of reliable data that could render its subsequent simulations more realistic. In addition to integrating data from case studies and statistical surveys, the model provides a mechanism for carrying out a continuing assessment and synthesis of research results from the

various projects in the field, indicating the significance of new findings and identifying important areas of ignorance requiring further exploration. In a dynamically developing area such as the study of technological innovation, effective exercise of this function can prove crucial.

(3) Framework for Specific Research Projects. The model should also be used as the framework for conceiving and conducting specific research projects in depth in particular areas of the system. In this connection, the model can prove of most assistance in suggesting specific projects to be undertaken, in assessing their anticipated significance to the total system, and in designing the research in such a way as to assure attention to all relevant factors, including those in other segments of the system.

(4) Comparative Analyses. A fourth major application of the systems model is the conduct of comparative analyses of the varying functioning of technological innovation along a number of significant dimensions, such as: organizational relationships and characteristics; environmental conditions and constraints; types of innovations; sectors of the economy; specific kinds of industries; and different regions of the

country. For each situation to be studied, 'innovational profiles' can be developed, consisting of typical configurations of institutions, organizations, policies, goals, resources, and patterns of technological knowledge and communication characteristic of innovation in that situation. Profiles can also be delineated which take account of several dimensions simultaneously (e.g., contrasting the functioning of innovation in the defense and non-defense sectors of specific industries; or in the area of aerospace systems compared with complex socio-economic systems in urban affairs, transportation, education, pollution controls, etc.). As with the restated case studies, the 'innovational profiles' would provide compatible data on the functioning of innovation along a variety of important dimensions. The profiles would be subject to comparative analysis regarding the points of similarity and differences in the fulfillment of each function in the varying situations.

(5) Aid to Administrators and Policy Makers. The fifth major application of the systems model is to assist administrators and policy makers in the evaluation of research results, proposals for new research and studies, and specific policy alternatives and recommendations. The model could aid in evaluating research proposals and

results in relation to the total body of existing knowledge, and to significant areas of ignorance requiring further exploration. Similarly, the model can be used in suggesting and evaluating specific policy alternatives and recommendations, stressing their strategic significance to the overall processes of technological innovation.

(6) Aid in Education. As its sixth major application, the model constitutes a comprehensive framework for an intensified educational program. The model can assist in the design and stimulation of a variety of seminars, symposia, and training programs, each specially tailored and directed toward key audiences in this area: researchers in the field; practitioners in a variety of industries and different kinds of organizations; decision makers at different levels in different sorts of institutional contexts; and high level policy makers whose decisions affect the overall environment in which innovation must occur. This educational function may well prove to be the most important application of the model. For in the final analysis, enhancing the processes of technological innovation depends on the enhanced understanding of individuals, whose

imagination, judgment and commitments shape the success and consequences of technological innovation. The systems model set forth in this report can make a major contribution toward imparting such understanding.

H - Conclusion

In closing, one basic characteristic of the system deserves further emphasis. This is the fact that the model considers the functions involved in technological innovation as constants, and views the configurations of institutions and organizations engaged in carrying out those functions as variables. Thus the model focuses attention on the vast opportunities afforded to alter existing configurations and create new configurations of institutions and organizations, with the aim of enhancing the processes of innovation. 'Institutional innovation' of this sort is certainly not a new phenomenon or one peculiar to technology related activities. The evolution of the socio-economic system has always exhibited a certain amount of 'institutional innovation', although one might be able to substantiate that the extent and rate of 'institutional innovation' in our time is greater than it has been heretofore.

In any event, it is shortsighted, indeed, to assume that the pervasive and profound impact of technological change on our socio-economic system will not entail and evoke corresponding changes of significance in the structure of institutions and organizations through which technological changes occur. Such institutional innovations are, of course, already beginning to abound in fact or in proposal. Examples include: the rise of the contract research firms such as RAND; the emergence of public-private corporations to exploit new technologies, such as COMSAT; the proliferation of specialized scientific and technical information services; the extension of governmental efforts in this area, such as the Office of State Technical Services, or sponsorship of Small Business Investment Corporations; and various recent proposals, such as those to establish a National Institute of Technology, or to transform the great national laboratories into broader

based institutions capable of coping with a much wider range of socio-economic issues.

But these instances - significant though each of them may be - barely skim the surface of the untapped reservoir of possibilities for 'institutional innovation'. The systems model provides a powerful analytical tool for exploring this reservoir of possibilities. Within its framework of interrelated functions, one can conceive, construct, and appraise a host of new institutional and organizational arrangements for performing the various functions. The imaginative creation of new institutions to operate at strategically significant points of the system could have profound consequences for the processes of innovation in our society. The whole area of conversion processes provides a fertile field for such exploration. If it should be the case that this model serves to stimulate new ideas - and to assist in evaluating existing ideas - for institutional innovations, this accomplishment may well prove to be its most valuable contribution.

Of course the real value of the model - as is the case with all research results - must remain largely undetermined until its potential has been widely explored and enough of its applications have been implemented. This process of exploration and implementation can be carried out only through the concerted efforts of a number of researchers and decision makers throughout this area, who may be stimulated to subject the conceptual system to the intensive scrutiny and critical analysis necessary to transform it from an invention into an innovation: that actually serves to enhance the processes whereby other innovations emerge.

The aid of all those who may be so impelled is earnestly entreated.

A

BIBLIOGRAPHY

ON

TECHNOLOGICAL INNOVATION

NOTE:

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